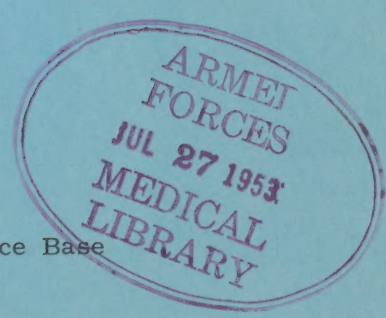


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MINUTES AND PROCEEDINGS
of the Thirty-first meeting of the
ARMED FORCES-NRC VISION COMMITTEE
November 20-21-22, 1952



Wright-Patterson Air Force Base

Dayton, Ohio

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of the Thirty-first meeting of the
ARMED FORCES-NRC VISION COMMITTEE

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Minutes of the Thirty-first Meeting

November 20-22, 1952Wright-Patterson Air Force Base
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Dr. C.L. Kraft
H.P. Ruffell Smith

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Mr. Wilson P. Tanner, Jr.
Wing Comdr. J.B. Wallace
Mr. Alexander Weisz
Mr. Hugh Welsman
Mr. Joseph W. Wulfeck

VISION COMMITTEE SECRETARIAT

Dr. H. Richard Blackwell
Dr. John H. Taylor
Mrs. Nita Norman

~~RESTRICTED~~

INDEX TO THE PROCEEDINGS

Thursday, November 20

1. Brig. Gen. Otis B. Schreuder, of the Air Materiel Command, officially welcomed the Vision Committee members and guests to Wright-Patterson Air Force Base, and gave a brief, informative statement about the Base, its facilities and activities.
2. The Chairman, Col. Victor A. Byrnes, read a memorial statement to Dr. Richard G. Scobee, former member of the Vision Committee, and asked if the members would like to dedicate this 31st meeting of the Vision Committee to Dr. Scobee. It was moved by Dr. John L. Matthews, and seconded by Brig. Gen. Earl Maxwell, that the meeting be so dedicated. The memorial statement is included in the Proceedings. 23
3. The Chairman called for corrections or additions to the Minutes of the 30th meeting. A correction was offered by Lt. W. J. White, which is reported in the Proceedings 25
4. Lt. Col. George O. Emerson presented a paper entitled "Some Air Force Visual Problems." The text of the report is contained in the classified Supplement to the Proceedings.
5. Brig. Gen. Earl Maxwell presented a paper entitled "Visual Factors in Aircraft Accidents," a summary of which is contained in the classified Supplement to the Proceedings.
6. Mr. C. Colbert presented a paper entitled "Cathode Ray Tube Displays," the text of which is contained in the classified Supplement to the Proceedings.
7. Lt. C. P. Crocetti presented a paper entitled "Visibility of Radar Signals With a Photographic Projection System (Target Position Indicator)." The text of the report is contained in the Proceedings 26
8. Mr. A. Z. Weisz presented a paper entitled "An Experimental Technique for the Investigation of the Legibility of Letters Printed by Means of an Elemental Facsimile Printer and Degraded by Gaussian Noise." The text of the report is contained in the Proceedings. 31
9. Dr. L. A. Riggs presented a paper entitled "Recent Experiments on Visual Acuity in Relation to Eye Movements." The text of the report is contained in the Proceedings. 37
10. Dr. H. R. Blackwell presented a paper entitled "A Study of White Light 'Photosensitization.'" The text of the report is contained in the Proceedings 43
11. Dr. W. J. Crozier presented a paper entitled "On Incremental Visual Intensity Thresholds." The text of the report is contained in the Proceedings 48
12. Dr. R. Tousey presented a paper entitled "Night Myopia and Photography of the Purkinje Images." The text of the report is contained in the Proceedings 53

13. Dr. M. J. Allen presented a paper entitled "Effect of Flashes of Light on Night Visual Acuity, Part II." The text of the report is contained in the Proceedings. . . 59
14. Dr. Henry A. Knoll presented a paper entitled "The Effect of Low Levels of Luminance and Freedom from Optical Stimulation of Accommodation upon the Refractive State of the Eye." The text of the report is contained in the Proceedings . 76

Friday, November 21

15. Dr. J. E. Uhlaner presented a paper entitled "Development of a Mesopic Test of Night Vision Performance." The text of the report is contained in the Proceedings . 87
16. Dr. Glenn A. Fry presented a paper entitled "Effect of Flashes of Light on Night Visual Acuity, Part I." The text of the report is contained in the Proceedings . . . 94
17. Maj. E. L. Cole presented a paper entitled "Effects of Two Instrument Lighting Systems on Dark Adaptation." The text of the report is contained in the Proceedings. 123
18. Lt. S. C. McLaughlin, Jr., presented a paper entitled "The Acceleration of Dark Adaptation by Controlled Red-Light Exposure." The text of report is contained in the Proceedings 133
19. Subsequent to the meeting, Dr. Walter R. Miles submitted to the Secretariat a paper entitled "Effectiveness of Red Light on Dark Adaptation." The text of this paper is included in the Proceedings because of its relevance to the foregoing paper. 139
20. Dr. Alphonse Chapanis presented a report of the working group on Chart Reading Under Red Illumination, the text of which is contained in the Proceedings 152
21. The Vision Committee approved the following recommendations made by the working group on Chart Reading Under Red Illumination:

RECOMMENDED THAT OPERATIONAL REQUIREMENTS FOR DARK ADAPTATION IN MILITARY AND CIVIL AVIATION BE STUDIED. AS PART OF THIS STUDY, THE GROUP RECOMMENDED THAT SUMMARY JOB ANALYSES BE PREPARED FOR ALL AIR CREW MEMBERS ABOARD VARIOUS TYPES OF AIRCRAFT TO FIND OUT FOR WHICH CREW MEMBERS COMPLETE DARK ADAPTATION IS ESSENTIAL, FOR WHICH ONES SOME DARK ADAPTATION IS NECESSARY, AND FOR WHICH ONES NO DARK ADAPTATION REQUIREMENT EXISTS. FINALLY, THE GROUP RECOMMENDED THAT RESEARCH BE INITIATED ON THE COLLATERAL PROBLEMS OF (1) THE IMPAIRMENT OF VISIBILITY OUTSIDE THE AIRCRAFT CAUSED BY DIRTY WINDSHIELDS, REFLECTIONS FROM WINDSCREENS, AND SO ON, AND (2) THE RELATION BETWEEN DARK ADAPTATION AS USUALLY MEASURED AND THE DETECTION OF LOW CONTRAST TARGETS UNDER SERVICE CONDITIONS, ESPECIALLY AT HIGH SPEEDS.

RECOMMENDED THAT PRIORITY BE GIVEN TO THE COMPILATION OF A BIBLIOGRAPHY OF LITERATURE, AND A CRITICAL EVALUATION OF THIS LITERATURE, TO SEE WHAT IS KNOWN AND WHAT IS NOT KNOWN ABOUT THE EFFECTS OF PRIOR LIGHT ADAPTATION UPON THE INSTANTANEOUS THRESHOLD AND SUBSEQUENT DARK ADAPTATION.

RECOMMENDED THAT DR. MASON CROOK BE ENCOURAGED TO CONTINUE AND COMPLETE HIS WORK.

22. LCDR. Dean Farnsworth presented a paper entitled "Considerations in the Choice of Brightness Levels for Red Lighting." The text of the report is contained in the Proceedings.	163
23. Dr. J. W. Wulfeck presented a paper entitled "Progress Report on the Design of Aeronautical Maps and Charts for Use Under Red Light." The text of the report is contained in the Proceedings	170
24. Dr. K. N. Ogle presented a paper entitled "A Study of the Subjective Depth Values and Precision of Stereoscopic Depth Perception With Double Images." The text of the report is contained in the Proceedings	178
25. Dr. G. S. Harker presented a paper entitled "The Stereoptometer--An Instrument for the Study of Binocular Vision." The text of the report is contained in the Proceedings	182
26. Dr. W. Gogel presented a paper entitled "The Perception of the Depth Position of an Object as a Function of Other Objects in the Field of View." The text of the report is contained in the Proceedings	187
27. Dr. L. L. Sloan presented a paper entitled "Aniseikonia and the Howard-Dolman Test." The text of the report is contained in the Proceedings	194
28. Dr. P. A. Cibis presented a paper entitled "Irradiation and Stereoscopy." The text of the report is contained in the Proceedings.	201
29. Dr. H. W. Rose presented a paper entitled "Protection Against Eye Damage from Atomic Explosions." The text of the report is contained in the Proceedings . . .	205
30. Lt. W. J. White presented a paper entitled "Changes in Visual Function as a Result of Gravitational Stress." The text of the report is contained in the Proceedings	209
31. Maj. J. A. Buesseler presented a paper entitled "Glaucoma Detection Program at Wright-Patterson Air Force Base." The text of the report is contained in the Proceedings	215
32. Col. Jack Bristow presented a paper entitled "Problems of the Use of Corrective Lenses and Filters with Oxygen Masks." The text of the report is contained in the Proceedings.	222

Saturday, November 22

33. Lt. Col. George O. Emerson and Mr. H. C. Glover presented a report entitled "High Altitude Visibility." The text of the report is contained in the Proceedings	227
34. Dr. S. Q. Duntley presented a report of the working group on Visibility at High Altitudes. A summary of the report is contained in the Proceedings.	232
35. Mr. C. A. Douglas presented a paper entitled "Some Factors Affecting the Relation Between Reported Visibility and Visibility from Aircraft." The text of the report is contained in the Proceedings	235
36. Dr. H. R. Blackwell presented a paper entitled "Foveal Detection Thresholds for Various Durations of Target Presentation." The text of the report is contained in the Proceedings	249

37. Group Capt. Clement McCulloch presented a paper entitled "The Field of Vision and Its Significance When Projected Into Space." The text of the report is contained in the Proceedings. 258
38. Dr. H. R. Blackwell presented a report of the working group on Tank Searchlights. The text of the report is contained in the Proceedings. 270
39. Dr. H. R. Blackwell presented a paper entitled "The Influence of Yellow-Tinted Glasses Upon Visibility at Low Luminance." The text of the report is contained in the Proceedings. 302
40. Maj. Marvin E. Kay presented a paper entitled "Night Tactical Bombardment Visual Problems in Korea." The text of the report is contained in the classified Supplement to the Proceedings.
41. Mr. R. Nierenberg presented a paper entitled "Proposed Study of Visual Reconnaissance." The text of the report is contained in the classified Supplement to the Proceedings.
42. Mr. George W. Stickle presented a paper entitled "Identification Point for Low Altitude Bombing." The text of the report is contained in the classified Supplement to the Proceedings.
43. Dr. S. Q. Duntley presented a paper entitled "The Limiting Capabilities of Unaided Human Vision in Aerial Reconnaissance." The text of the report is contained in the Proceedings. 312
44. Lt. Col. Elwin Marg presented a paper entitled "Aircraft Periscopes for Pilotage and Search." The text of the report is contained in the classified Supplement to the Proceedings.
45. Dr. S. S. Ballard announced that the International Commission of Optics will hold its third regular congress in Madrid during April 1953. The text of this announcement is contained in the Proceedings. 321
46. Mr. C. H. Baker announced that the Canadian Defense Research Board, in connection with its work on radar problems, has accumulated a great deal of literature on this subject. A guidebook or bibliography of radar literature has been compiled. It will run to approximately 150 pages and Part I is currently in press. Free copies will be available upon request to Mr. Baker.
47. The Chairman asked that Dr. W. S. Verplanck's report of the working group on Illumination and Dark Adaptation be read into the Minutes. The text of the report is contained in the Proceedings. 322
48. The Chairman asked that Dr. Paul M. Fitts' report of the working group on Airfield Taxiway Lighting and Destination Marking Systems be read into the Minutes. The text of the report is contained in the Proceedings. 325
49. The Chairman asked that Dr. K. N. Ogle's report entitled "International Nomenclature for Designating Visual Acuity" be read into the Minutes. The text of the report is contained in the Proceedings. 328
50. In closing the sessions, Col. Byrnes reminded the Committee that this 31st meeting of the Vision Committee had been dedicated to the memory of Dr. Richard G. Scobee. Col. Byrnes felt that Dr. Scobee would have enjoyed the sessions and the many fine papers presented, and that the meeting was very worthwhile and deserving of its dedications.

51. THE NEXT MEETING OF THE VISION COMMITTEE WILL BE HELD APRIL 2-3-4
AT THE NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA.

52. Abstracts. 343

IN MEMORIAM



Richard Gordon Scobee (1914 - 1952)

The first formal action taken by the Armed Forces-NRC Vision Committee at its 31st meeting was a unanimous vote to dedicate the meeting to the memory of the late Dr. Richard Gordon Scobee. Col. Byrnes, Chairman, made the following memorial statement:

"Since the last meeting of this organization, we have lost one of our most distinguished members, Dr. Richard Gordon Scobee. It was at a Vision Committee meeting in Washington in the spring of 1951 that Dr. Scobee had his first symptoms of the disease that caused his death. In spite of warnings to take life easy, he never missed a Vision Committee meeting until this one. He had tremendous interest in this group and its work and he took a great deal of pride in its accomplishments. As its chairman for the period 1948-50, his never-failing good humor, earnestness and enthusiasm were responsible in no small measure for the success of its meetings.

"His own accomplishments in the field of ophthalmology were unequaled by anyone of his age. With his teaching, his clinics, and his surgery, the presentation of his many papers and his book, 'The Oculo-rotary Muscles,' he earned a niche for himself which will endure. In addition to his scientific interests, he was a real friend to a great many members of this Committee.

It is most appropriate that you have elected to dedicate this 31st meeting of the Vision Committee to the memory of Dr. Richard Gordon Scobee."

CORRECTION TO THE MINUTES AND PROCEEDINGS OF THE THIRTIETH MEETING

The authors of the paper entitled "The Effect of Viewing Angle and Parallax Upon Accuracy of Reading Quantitative Scales" would like to correct an error that appeared in the Minutes and Proceedings of the Thirtieth Meeting of the Armed Forces-NRC Vision Committee. The graph shown in Figure 5 on page 31 is not correct. The correct graph is a plot of median average error as a function of viewing angle, and it is reproduced below.

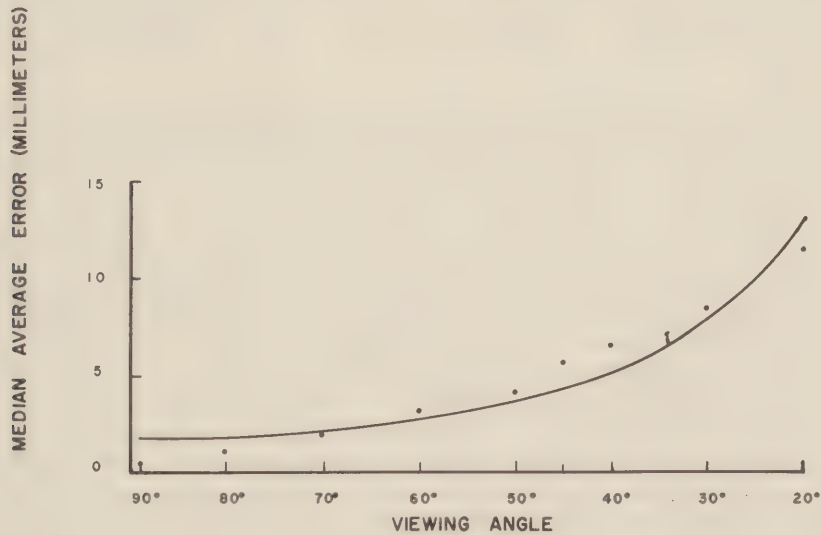


FIGURE 5. MEDIAN AVERAGE ERROR FOR ALL POINTER - MARK
DISPLACEMENT AT EACH VIEWING ANGLE .

Figure 5. Median Average Error for All Pointer-Mark Displacement at Each Viewing Angle.

REF ID: A66000

VISIBILITY OF RADAR SIGNALS WITH A PHOTOGRAPHIC PROJECTION SYSTEM (TARGET POSITION INDICATOR)¹

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This paper presents the results of an investigation in which two radar systems have been comparatively evaluated, and discusses certain procedural considerations which were encountered. The two systems under consideration are the Target Position Indicator, or TPI, and the present conventional method of direct viewing of a 12 BP7, Plan Position Indicator. The primary basis for the comparison of these two systems is, for the purposes of the present paper, the relative visibility of radar signals with the TPI and the P7.

A description of the TPI equipment will prove helpful to those who are not acquainted with it. The Kenyon TPI, as depicted in Fig. 1, is designed for use in Air Defense GCI stations and is meant to eliminate the teller-plotter link in present systems by combining the scope-reader and plotter functions into one operation. The system accomplishes this by employing two stages for the processing of radar information. In the first stage, a series of projected photographs of raw radar data is presented to a team of plotters whose task it is to derive an integrated, filtered, and coded display of the immediate air situation. The initial step in the sequence of activities required to achieve this objective is the photographing of successive PPI radar scans by the first stage camera. Following a ten second exposure to the PPI (determined by a 6 RPM antenna rotation rate), the exposed frame is developed, while the succeeding frame is exposed. Ten seconds after the end of exposure to the PPI, the developed frame is projected by an optical lens system upward onto an intersticed projection surface on the bottom of the horizontal plotting board. The team of plotters, marking on the plexiglass upper surface of the horizontal board with china pencil, establishes tracks by connecting the positions of a given target in successive frames. As it becomes available, pertinent operational information is added to the tracks in coded form.

In the second stage of the TPI system, the filtered representation of the air situation produced by the plotting team is transferred to a larger vertical display for use by GCI personnel charged with monitoring the air situation. This final display is achieved by periodically (about once every 6 sec.) photographing and projecting the filtered track information displayed on the horizontal board. In order to permit the photographing of the filtered display, the china pencil marks are fluoresced by ultra-violet edge-lighting of the horizontal board. The second stage camera photographs the filtered display from beneath the horizontal board and the associated projector throws the developed image onto the rear of a vertical transmission

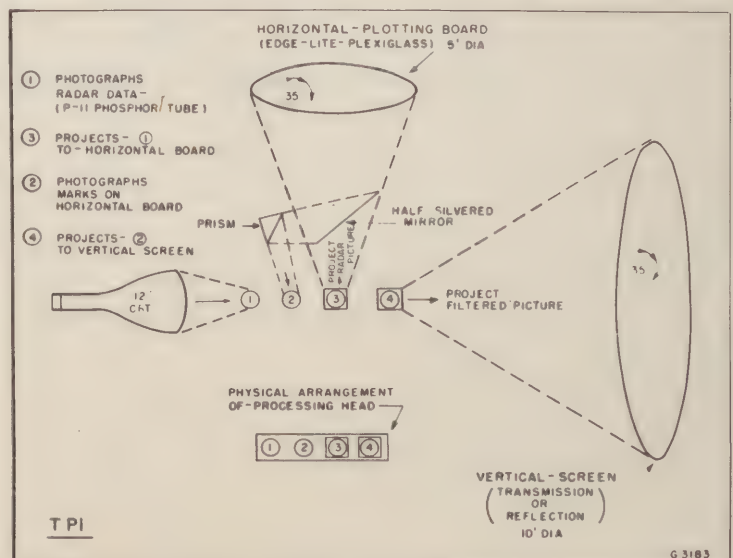


Figure 1. A schematic drawing of the TPI showing the sequence of operations of the equipment.

¹Experiment conducted by J. F. Corso, D. E. Page, and C. P. Crocetti.

REF ID: A66000

type screen. The primary concern of this paper is to determine what relative loss or gain in visibility, by the use of this technique, might be expected to result as compared with the use of direct viewing of a P7. For this purpose, therefore, we are concerned only with the first equipment stage of the TPI.

A comparative evaluation of two radar systems involves the consideration of a large number of parameters. In some cases, one may assume that a single value for certain parameters of both radar systems will not influence the generality of the comparative results. This situation exists, for instance, for those parameters which can be assumed to have only certain fixed values in actual operation, due to requirements imposed by the design of the system. In an evaluation of the two systems, therefore, one simply guarantees that representative parametric values are employed. Similarly, in the comparison of the systems, one might also assume that changes in the value of certain parameters would lead only to changes in the absolute visibility of both systems, without radically affecting the relative differences between the systems.

In the case of a few parameters however, the assumption that a single identical value for both systems will not influence the comparative differences between two systems under study is not justifiable. Two such parameters are those of grid bias settings, or trace brilliance, and video gain settings, or the general background noise level.

It has been demonstrated quite clearly that there is an optimal bias level and this data is easily reconcilable with existing visual data on brightness discriminations. A brief statement as to the cause of this optimum would indicate that the low background brightnesses resulting from low bias levels requires proportionately greater signal intensities which is as predicted by the relationship of threshold $\Delta I/I$ to I ; high bias levels, on the other hand, tend to lead to saturation of the light out-put characteristics of the cathode ray tube thereby also requiring higher than minimal signal intensities or threshold. Since the relationship between bias level and light out-put is most probably different for different cathode ray tubes, one cannot assume that the same bias level is optimal for both systems nor that differences between the systems obtained at a given bias level are representative of differences between the systems.

The consideration of the variable of general noise level is not at the present time based upon such well founded data as that for grid bias considerations. Generally, there are certain similarities in the two problems. On intensity modulated scopes, noise can be considered to have a double effect. High frequency noise leads to a very fine speckled grain upon the scope face. Since this high frequency noise is random and appears rather uniformly over the scope face, one may consider that its effects upon visibility are similar to the effects of grid bias, namely that the general background brightness level is increased by increasing amounts of noise. If one were to consider only high frequency noise, therefore, the detrimental effects could be overcome by compensatory decreases in the bias level, since the problem should be simply one of guaranteeing that an adequate background level of the radar picture was obtained. Low frequency noise, however, presents problems which cannot be compensated for by changes in grid bias. Since low frequency noise is not uniformly distributed over the scope face and does not have an apparent fine texture but rather leads to clusters of bright spots at only selected positions, an attempt to correct for the presence of noise at a particular point on a tube face will lead to a lower than optimal bias level upon noise free portions of the tube. Since radar noise is composed of both low and high frequency components, one may expect that only certain amounts of the detrimental effects of noise can be overcome by an adjustment in optimal grid bias.

Again, since two different radar systems with different cathode ray tubes are under consideration, one cannot assume that the specification of a single noise value will lead to a representative difference in the two systems and it is therefore required to vary the parametric value of noise.

An adequate specification of visibility for the two systems requires that the measure be expressed in terms of threshold signal-to-noise ratio, since, from an engineering point of view, there is no limit to be placed upon absolute signal intensity but, rather, only upon this measure of signal-to-noise ratio. If it were not for the fact that noise is amplified to the same extent as the signal, one could simply increase the video gain to improve the return from small echoes. Similarly, from a visual point of view, it is necessary that the noise level be varied in the study to assure that an optimal operating level for each system has been attained. This is to insure that a minimal signal-to-noise ratio is obtained for each system since the effects of noise on intensity modulated scopes results in higher than minimal signal-to-noise ratios for both low and high noise levels. At low noise levels the threshold signal-to-noise is high as a result of the limiting factors of the absolute threshold of the human eye and/or film for signal intensity. At high noise levels a higher than minimal signal-to-noise ratio results from the detrimental effects of low frequency noise previously specified.

The use of actual aircraft for detection studies requires a degree of experimental control not easily attainable. While other factors such as movement and shape of targets, may enter into the identification of a signal as an aircraft, the limiting factor of detectability of radar returns is that of visibility, and this study therefore emphasizes this latter factor.

In this study, synthetic signals were employed with signal voltage determined at the point of entry into the two cathode ray tubes and attenuation measurements made from equated voltages at this point. One may consider, therefore, that the differences obtained between the two systems would apply regardless of the type of radar set, providing other factors such as pulse repetition frequency and beam width were not radically changed. Other than the equipments under test, the major pieces of apparatus employed were a video mapping console and mixing unit which allowed for the presentation of a stationary target at any of 12 different azimuth positions. Target size was 2.0° beam width, with a pulse repetition frequency of 207. Pulse length was 7.5 micro-seconds, on a range scale of 90 miles. Antenna rotation rate was 6 RPM. The voltage of the signal from this apparatus could be varied in one db steps from an initial level of 13.5 volts by means of a Leeds and Northrup attenuator.

Since the problem of simulating noise has never been adequately solved at a technical level (mainly as a result of difficulties in duplicating spectral characteristics), the actual noise generated by the radar system was employed. Noise level was varied by means of a separate attenuator in the circuitry. The radar antenna was short-circuited to remove ground clutter and uncontrolled targets. The intensity of an initial reference of 13.5 volts for noise was measured on a "A" scope, as were all readings which were employed to calibrate the attenuators, and guaranteed that all amplifiers were operating at linear and undistorted levels.

This investigation employed two subjects, each of whom served alternately with the TPI equipment and direct viewing of a 12BP7. Stimuli were presented by a modified method of limits which increased the signal strength from a value below threshold in one db steps. Prior to the determinations of threshold, an optimal grid bias was obtained for each noise level by empirical evaluation of minimal threshold. In all phases of the study except one, the subject was told the exact position of the target. In one phase, however, the target appeared in any of 12 positions randomly, so that the effects of angle of view, "awareness" of position, and area of responsibility might be evaluated.

Fig. 2 presents threshold signal strength (as measured in db attenuation from 13.5 volts) as a function of the intensity of noise (again, db attenuation from 13.5 volts). The data represented in this figure and those in the next figure have been obtained after the optimal grid bias had been determined at each noise level. Small changes in grid bias were

found to be more critical as the amount of noise in the system decreased, with a change of one volt leading to a 2.5 db loss in detectability at low noise levels; thus the tube was operated at its optimal bias level for each noise value employed. In a general way, the results confirm theoretical expectations for the effects of noise. As Fig. 2 demonstrates, a certain minimal signal strength is required for very low noise values; with a great deal of noise, more signal voltage is necessary to make the pips visible. An original investigation concerned only with the relative sensitivity of the two systems indicated that, under "no noise" conditions, a difference of 12 db in favor of direct viewing was obtained. This is roughly comparable to the difference for low noise levels reported in the present study.

The order of magnitude (in volts) of the results for PPI direct viewing are in general agreement with those previously reported which indicate a threshold of P7 tubes of approximately 0.5 volts under "no noise" conditions. The effects of noise become quite marked for the P7 at about 2.5 volts, while TPI appears to continue to function at its minimal signal level until the noise reaches approximately 5 volts. For higher levels, both functions break quite markedly and in fact, TPI operates more effectively at high noise levels than the P7.

In order to determine the minimal signal-to-noise ratios for each system, the data have been replotted as in Fig. 3. The ordinate expresses the scale in terms of db attenuation of the signal with respect to the noise. Since both axes of Fig. 2 are logarithmic scales, the ordinate in this figure has been obtained by subtracting noise level from signal level. Previous data with this type of function are not known to exist, but at least one other study has reported signal-to-noise ratios on P7 tubes as low as -18 db. It should be pointed out that these signal-to-noise ratio values for both TPI and PPI are probably smaller than those encountered in operational situations because, in this laboratory study, the operators knew where the target was to appear and all components of the equipment, including the cathode ray tube bias were set for optimal performance. In other words, these measurements represent laboratory ideals for each of the two systems as they are presently developed.

The curves in Fig. 3 are of importance in that they indicate that a minimal

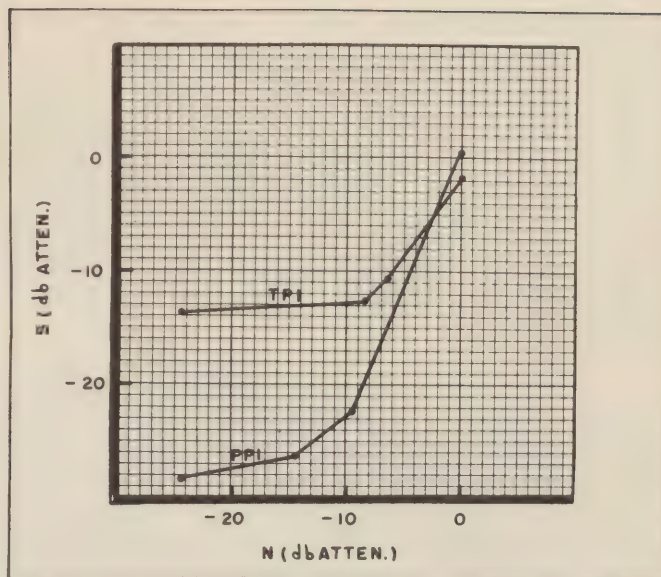


Figure 2. The functions relating signal intensity to noise level for the TPI and P7 as measured in decibel attenuation from 13.5 volts.

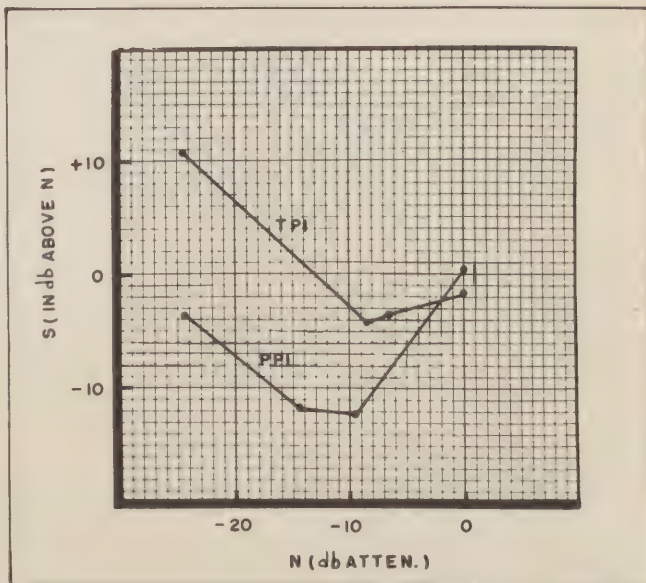


Figure 3. The functions relating S/N ratio to noise level for the TPI and P7 as measured in decibel attenuation from 13.5 volts.

signal-to-noise ratio occurs for both TPI and the P7 at approximately 5.4 and 3.4 volts of noise respectively. In the lower range of noise levels, signal-to-noise ratio decreases since threshold signal intensity, being relatively constant in this range, increases less rapidly than the noise intensity. For the P7, the minimal signal-to-noise ratio is -12.2 db and for TPI is -4.1 db. This difference of 8.1 db in favor of the P7 at the minimal signal-to-noise ratio for each system will manifest itself in an approximately 38 percent decrease in range performance for TPI, all other parameters for the two systems held constant. When each of the two systems is at its peak of operation for receiver gain, cathode ray tube bias setting, etc., then the P7 permits better detection. As presently developed, the addition of a TPI link into the detection system will cause a loss in range performance of approximately 38 percent.

The results from this study should not, of course, be generalized to all photographic systems, since changes in design characteristics will largely determine the efficiency of the photographic system. At present, evaluations on a revised model of the TPI are under way and some improvement is already evident as a result of changing film type, lens system, and other factors. The major emphasis of this paper has been to stress the importance of attaining an optimal operating noise level in order to insure that evaluations between the visibility of two radar systems compare optimal performances for each.

AN EXPERIMENTAL TECHNIQUE FOR THE INVESTIGATION
OF THE LEGIBILITY OF LETTERS
PRINTED BY MEANS OF AN ELEMENTAL FACSIMILE PRINTER
AND DEGRADED BY GAUSSIAN NOISE

Alexander Z. Weisz

Tufts College

Introduction

The Infomax project is supported by a contract between the Communication and Navigation Laboratory of the Air Materiel Command and Hogan Laboratories, Incorporated. Dr. R. M. Fano, Assistant Professor of Electrical Engineering at M.I.T., is associated with the project as a consultant on information theory. The Institute for Applied Experimental Psychology of Tufts College holds a subcontract with Hogan Laboratories. The psychological research with which this report is concerned has been carried out under the direction of Dr. Mason N. Crook.

The purpose of the project is to investigate the legibility of noise-degraded printed materials in which characters are synthesized from dot or stroke elements by means of elemental printers, to determine so far as possible an optimum system for such printing, and to design and produce a "breadboard model" of communication equipment based on the results of these investigations. The general program of the investigation was planned on the basis of an analysis of problems of visual communication in relation to noise perturbation by the Communication and Navigation Laboratory of the Air Materiel Command.

At the inception of the project it was decided to prepare experimental test materials for the legibility experiments by means of facsimile communication equipment. Facsimile is probably best known as the means used to transmit the wire photos reproduced in the newspapers. In a facsimile communication link the printed or pictorial material to be transmitted is photoelectrically scanned in narrow strips or lines. The resulting signal is sent over a wire or radio channel to a recorder unit. The recorder ordinarily utilizes an elemental printer as one of its components. During transmission the facsimile signal is, in effect, broken up into a series of discrete impulses, so that the printer synthesizes the original pattern or picture by building it from a number of individual dot elements.

It was decided to use gaussian noise in the tests of legibility of characters degraded by noise perturbation. "White" noise, having a uniform mean energy level per cycle over the effective frequency range, was employed because (a) it can be adequately controlled for laboratory experimentation and (b) there is a sufficient background of knowledge so that a theoretical analysis of results is possible from the information theory point of view.

One feature of facsimile transmission is of particular interest in regard to legibility under noise degradation. The device does not make use of an electronic detector to separate out the desired signal from noise. For example: Teletype, which employs an electronic detector, will print each individual letter correctly under favorable conditions, but in the presence of excessive noise will print an incorrect letter or not print at all. Facsimile does not operate on an all-or-none basis. Both the letter signal and the noise arrive at the

printer and the combined signals are imprinted on the recording paper. It becomes the task of the human operator to pick out the correct information from the noise-degraded visual pattern.

Two major determinants of legibility related to characteristics of the facsimile equipment are S/N and definition. S/N is the ratio of signal intensity to noise intensity expressed in decibel units. Minus values denote signal strength lower than that of noise. Definition is, for our purposes, the number of printing elements per linear or square inch of copy. Definition may also refer to the number of elements in the linear dimensions or area of a square cell circumscribed about an individual letter.



Figure 1.

The appearance of noise-degraded facsimile copy is illustrated in Figure 1. Beginning with the card at the upper left and proceeding clockwise, the S/N values shown are -7, -9, -11, and -12 decibels. Definition is 20 elements in the vertical dimension of the letters.

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The Facsimile Equipment

Standard facsimile scanner and recorder units were modified by Hogan Laboratories and installed at Tufts College.

Clear copy is fed into the scanner, which scans it with 52 horizontal lines per inch.

The noise generator uses a gas tube with a permanent magnet as the noise source. By means of two step attenuators, the relative levels of signal and noise can be varied between ± 30 decibels in one decibel steps. The noise and signal currents are carried to the recorder on a common line where, depending upon momentary differences in phase and amplitude, they additively or subtractively combine.

The recorder utilizes electrolytic recording paper in the form of a continuous roll approximately nine inches wide. As the paper passes through the printer unit, marking current is supplied to it through a rotating helical electrode contacting the back of the paper and a linear electrode contacting the front surface. The recording paper turns dark by passage of the electrical current in proportion to the applied signal voltage. The linear portion of the optical density range of the paper is equal to approximately 1.

The recorder is designed to give an exact reproduction in size of the copy at the scanner. The individual printing elements of which the recorder copy is composed are roughly square in shape. Definition at the recorder is fixed at 52 lines per inch in both the vertical and horizontal dimensions, equaling 2704 elements per square inch.

A technique was devised for varying the definition of test copy. Photographic enlargements or reductions were used as copy at the facsimile scanner in the sizes necessary to subtend the desired number of elements per letter cell area. In the testing situation the sizes of the various definitions were equated by arranging the viewing distances so that in each case the retinal size of the letters was the same.

The Preliminary Experiments

The first objective of the experimental program was the investigation of the effect of the noise and definition variables on the legibility of individual letters. A series of preliminary experiments were undertaken to determine the general range of values within which it would be desirable to obtain more precise data and to answer a number of questions of experimental technique. Two of these earlier experiments were done with the purpose of determining the general shape of the performance curves for reading errors as a function of S/N for a number of definitions. Capital letters were presented in random order. The range of definitions employed was from 5 to 50 printing elements in the vertical dimension of the letters and the over-all range of S/N values from minus 21 to plus 9 decibels.

The Main Experiment

Having established the general form of the family of performance curves over a wide range of definitions and error levels, the decision was made to concentrate the data of the definitive experiment at the intermediate definitions and low error levels which were of greatest interest for the information theory analysis of the performance of the facsimile system.

Six definitions were selected, spaced between 10 and 40 elements per letter height, corresponding to letter cell definitions of 100 to 1600 elements. Three S/N values were employed at each definition, chosen so as to span a 2 to 20 per cent range of errors.

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Copy for the facsimile scanner was prepared in the form of scrambles of 26 letters; scrambles being drawn in random sets of four from four pooled alphabets. The scrambles were arranged in the format shown in Figure 1. The type face employed is gothic Tempo in a heavy stroke width. The spacing between letters corresponds to that on the typewriter where all letters are assigned equal amounts of space in the line.

Seventy-two scrambles were divided among the six definitions. Each of the scrambles was printed six times, twice at each of the three S/N values for that definition. This gave 432 stimulus cards, which were divided into 12 sets, each set being used as test material for two subjects.

In the test situation, stimulus cards were presented 8.5 inches behind an 11-inch square aperture in a vertical screen. Illumination at the reading surface was 72.9 foot-candles. A fairly high level of uniform general illumination was provided by banks of shielded lights along three walls of the experimental room.

The distances at which the subjects viewed the various definitions were chosen so that in each case the size of the letters was equal to 10-point type viewed at 14 inches. The subject was seated in a chair which could be accurately positioned at the viewing distances. A headrest was employed.

An experimental trial consisted of a reading of a 26-letter scramble. Thirty-six trials following an eight-trial practice series within a single experimental period provided data for the record. The instructions to the subjects emphasized accuracy rather than speed. Both time and error scores were recorded.

Twenty-four male subjects were selected for 20/20 visual acuity on the Ortho-Rater at near and far distances.

Results

The curves of Figure 2 show mean errors per trial plotted as a function of S/N for six definitions. The curves were fitted by inspection. All of the empirical points fall on their curves except the two lower points for definition 32. In this case the curve was smoothed to conform to the general pattern in this and previous experiments.

Standard errors of the plotted means were computed, and supplementary curves drawn through points one standard error above and below the main curves. It is apparent that, for the conditions of this experiment, the performance curves have been established within fairly narrow limits.

Figure 2 shows that for all error levels S/N decreases with increasing definition. These data

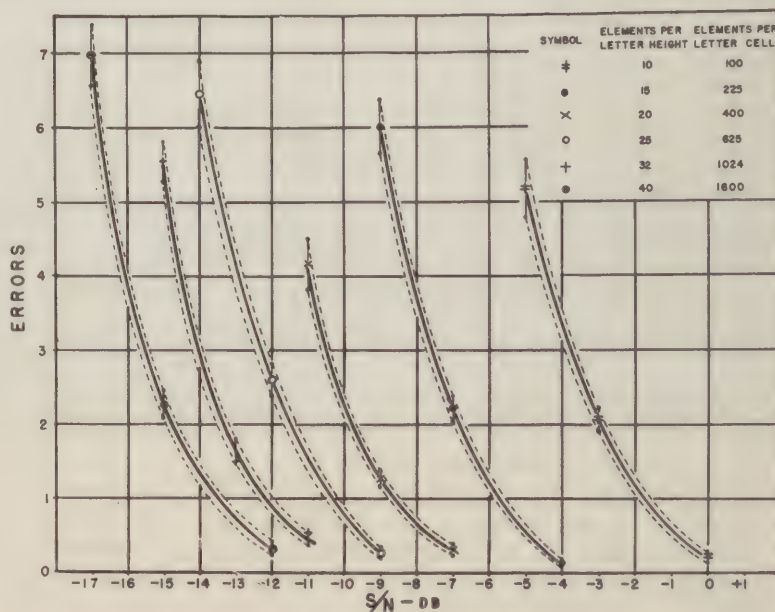


Figure 2. Errors as a function of S/N at various definitions (solid curves). Each plotted point represents the mean score of 24 subjects, two trials each. A trial consists of a reading of 26 scrambled letters. Dotted curves are drawn through points one standard error above and below the solid curves.

also substantiate the finding in our earlier experiments that, for each definition, errors increase rapidly as S/N falls below a critical level.

Discussion

It is difficult to relate these results to other work in visual acuity because of the uniqueness of the visual pattern presented by the noise-degraded copy.

We have computed relative contrast values according to the formula $\frac{B_1 - B_2}{B_1}$, between noise-degraded black and white areas printed at S/N values spanning the range employed in this study. At minus 17 decibels, relative contrast was computed as .26, and at zero decibels as .80. Within this range, contrast plotted as a function of S/N is essentially linear.

Weston employed a comparable range of contrast values in his study of the effect of brightness contrast in visual discrimination. Two of the illumination levels employed in his Landolt ring cross-out task bracket our value of 72.9 foot-candles. The smallest significant details of the letters employed in our experiment subtend a visual angle of 3.5', roughly comparable to the rings with 3' gap which Weston employed. Weston's data for accuracy of discrimination of position for rings of this gap-size show little or no difference within the range of contrasts tested. It appears that within the range of S/N and definition values of practical interest, contrast between letter and surround is not a significant determinant of legibility.

From inspection of the noise-degraded copy, the following appear to be of importance in determining legibility:

1. At the lower definitions, there is some distortion of the letter contour due to the size and shape of the individual elements of which the letter form is composed. At definitions above 10 or 15 elements per letter height, this factor appears to be of minor importance.

2. With increasing definition, lower S/N values must be employed in order to maintain a given error level. As the noise level is increased it affects the copy in two ways. The white background becomes increasingly more mottled in appearance. The individual noise elements conglomerate and fuse, so that the visual effect is of irregular black and gray units of increasingly larger size with smaller intervening areas of white and light gray. The noise also becomes increasingly effective in knocking out black elements within the letter outline, resulting in a more mottled letter area. As a result of these effects, the letter and surround become more similar in appearance and there is a decrease in the sharpness of the letter contour.

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Discussion

Dr. Wulfeck asked whether a facsimile transmitter could be fitted into a radar scope to produce controlled background noise such as Lt. Crocetti needed for his experiment. Mr. Weisz replied that he did not know what technical problems would be involved in such a development.

Dr. Blackwell commented on Mr. Weisz' conclusion that degradation of contrast was not an important variable in his experiment. This conclusion was based upon experimental data collected by Weston, in which there was little change in visual acuity with contrast changes of the order to be expected by contrast degradation. Dr. Blackwell suggested that Weston's data were not the most appropriate for use in this connection. In the first place, the Weston data represent a contaminated index of acuity in that speed and accuracy are combined into a single measure. Dr. Blackwell suggested that Mr. Weisz might well use instead the data of Connor and Ganoung appearing in the Journal of the Optical Society in approximately 1935. Dr. Blackwell stated that it was his recollection of the Connor and Ganoung data that there was an appreciable loss in visual acuity for change in contrast of the range involved in Mr. Weisz' experiment.

Mr. Weisz replied that he had not known of the Connor and Ganoung data and was pleased to know that they existed. He stated, however, that in using Weston's data he had used simple accuracy scores rather than the combined speed and accuracy scores.

RECENT EXPERIMENTS ON VISUAL ACUITY IN RELATION TO EYE MOVEMENTS

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Acknowledgments

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Dr. Floyd Ratliff, Dr. John C. Armington, Mrs. Janet Cornsweet and Mr. Tom Cornsweet conducted some of the experiments reported here.

Introduction

The main question underlying the present research is the following: Is visual acuity better when the eyes are effectively motionless, or do eye movements serve to improve visual acuity?

The answer to this question is not a simple one, but we are now in a position to draw definite though limited conclusions with respect to the influence of eye movements on the ability to see test objects. These conclusions are based upon our recent experiments on (1) the types and amplitudes of normal eye movement occurring during fixation on a test object, (2) a direct comparison of visual acuity scores with varying amounts of eye movement, and (3) measurements of acuity under the special condition in which eye movements are counteracted so that the retinal image of the test object remains stationary.

Normal eye movements

The most sensitive technique for measuring eye movements during fixation on a stationary test object involves the use of a mirror mounted on a contact lens. Control experiments have shown that a tightly fitted contact lens follows small motions of the eye without appreciable slippage. Fig. 1 shows the basic scheme¹ used in our published experiments on eye movements. Since the mirror is attached to the eye, rotation of the eye is recorded as a displacement of the image on the moving film. Fig. 2 is a photograph of the actual apparatus, in which vertical as well as horizontal components of the eye movements were recorded. Fig. 3 shows sample records obtained in an experiment² in which binocular recording was used. It is evident that the eye is relatively steady over short intervals of time, but that prolonged fixation involves greater and greater probability that the eye will exhibit a sudden jerk or slow wave covering several minutes of arc. Fig. 4 presents some measurements of the percentage of such records showing given amounts of eye movement, plotted as a function of the duration of exposure of the test object.³ It is evident that for very brief exposures the retinal image is essentially motionless, since even a motion of 5 sec. of arc is rather rare. The typical extent of eye movement rises rapidly, however, as the duration is increased until, for a one-second exposure, it is seldom that the eye fails to exhibit a motion of less than three min. of arc. Fig. 5 presents these data in the form of a log-log plot of median amplitude of eye movement as a function of exposure time.

Acuity determinations

Ratliff⁴ has reported direct determinations of visual acuity for short (.075 sec.) exposures of a grating type of test object. He recorded the horizontal movement of the eye

simultaneously with the measurement of visual acuity. He found that, in general, those exposures in which the eye showed little movement yielded higher acuity scores. Fig. 6, for example, it is seen that when the eye "drifted" more than 20 sec. of arc during the exposure there were significantly fewer correct judgments of the grating than when smaller amounts of "drift" were recorded. A similar, though less pronounced, effect resulted from a comparison of large and small amounts of eye tremor.

Recently we have approached the same problem through the use of a rather different experimental approach. We have "stopped" the retinal image of the test object with respect to the receptor cells. The arrangement for this is shown schematically in Fig. 7. Rays from a projector are reflected from a mirror on the eye and focussed on a screen. The image on the screen consists of a bright circle bisected by a fine vertical black line of variable thickness. The image is viewed over a path which effectively doubles the distance from the eye to the target. If the eye rotates through an angle α , the rays reflected to the screen are deviated through an angle 2α . Owing to the compensating path, rays from the screen enter the eye at an angle α . In effect, therefore, the eye and the image move through the same angle, so that the image of the target is "stopped" on the retina and covers the same retinal receptors regardless of eye movements. This arrangement was called Condition I in these experiments.

Fig. 8 shows the optical arrangements for Conditions I, II, and III. In Condition I the mirror M_2 on the contact lens C serves to keep the retinal image on one region of the fovea F_b , despite any motion of the image from I_a to I_b on the screen. In condition II, however, mirror M_2 is not on the eye, but is supported instead by a framework of the apparatus itself. Thus the image on the screen remains at I_a regardless of eye movements, and the retinal image moves to the right of the fovea as the eye is turned to the right. This condition is that of normal viewing of a test object. In Condition III, mirror M_2 is once more on the eye. A reversal of the viewing path has been produced, however, by the introduction of a dove prism at D . Now any movement of the eye to the right causes the retinal image to travel twice the normal distance with respect to F_b . In this condition, then, the normal eye movements have an exaggerated effect on the retinal receptors.

A desirable feature of the experimental design is that Conditions I and III are in fact identical except for the orientation of one of the dove prisms. Thus any observed differences in results with these two conditions may safely be attributed to the exaggerated motions of the retinal image in Condition III as opposed to the stopping of the retinal image in Condition I.

The different effects of the three experimental conditions were immediately noticed by both of the subjects. In Condition I the black line target was clearly seen when it first appeared. The subject was surprised by the fact that the line always appeared at the center of the field regardless of eye movements. Soon, however, the line began to fade out. Finally it disappeared altogether, so that the projected image seemed to consist only of a bright circular field. Occasionally the bright central field also disappeared. A fine black line usually disappeared during the first few seconds of viewing, and failed to reappear later. Heavier lines took longer to disappear and often reappeared from time to time during one minute of steady fixation.

Condition II was essentially a condition of normal viewing. The fading of the image did occur for the finer lines, but the lines reappeared sporadically. Heavier lines seldom disappeared.

In Condition III there was scarcely any disappearance of even the finest lines. The impression was that the target image was "locked into place" so that steady fixation was

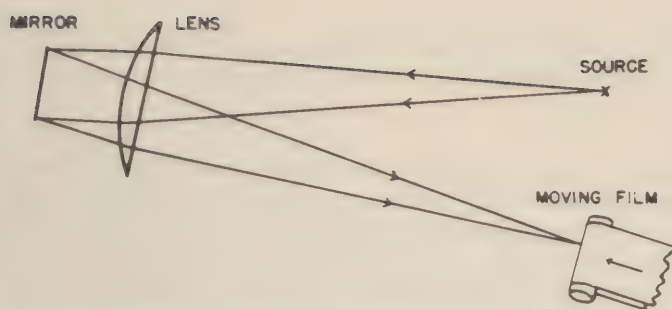


Figure 1. Scheme for recording eye movements.



Figure 2. Photograph of apparatus for recording eye movements.

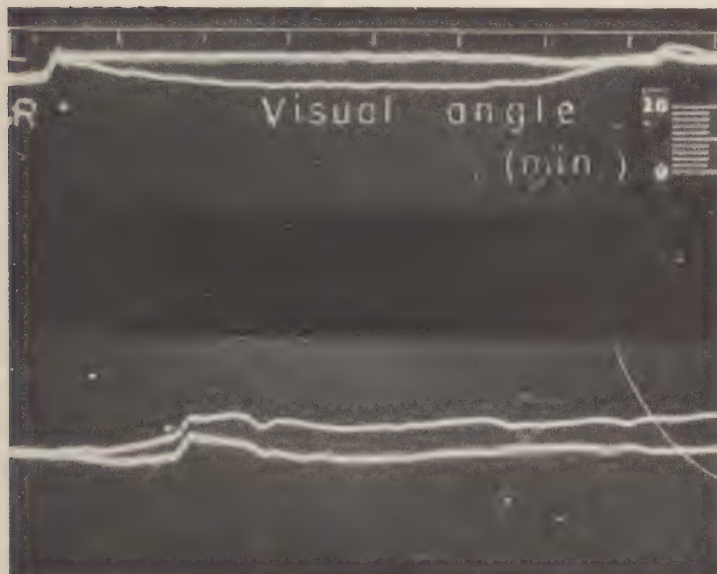


Figure 3. Sample records of eye movements. Simultaneous recording from right (R) and left (L) eyes. Extent of movement in the horizontal plane may be seen by reference to the scale (min. visual angle). Time (0.1 sec. units) is denoted by vertical lines at top.

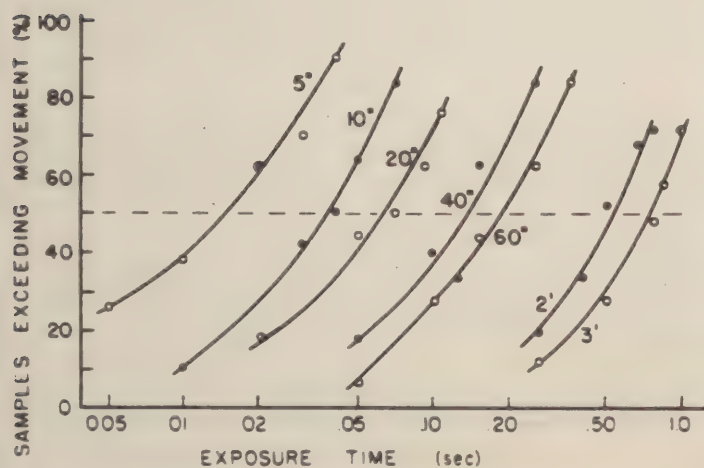


Figure 4. Probability plots of extent of eye movement as related to duration of viewing.

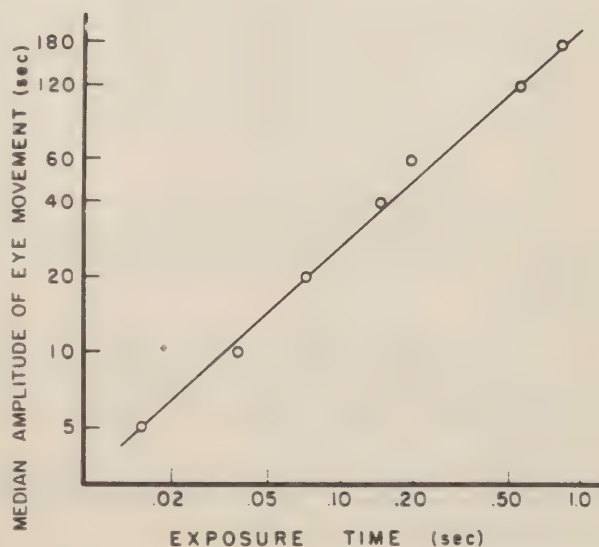


Figure 5. Median extent of eye movement as a function of duration of viewing.

effortless, automatic. It may be noted that in this condition the usual cues for fixation are exaggerated. The eye muscles are provided with double the normal feed-back from any drifting of the position of the eye.

For each different sized target line within each of the three experimental conditions, the percentage of its total exposure time during which the line was visible was determined. These percentages were plotted as a function of target width on arithmetic probability paper as shown in Fig. 9. It is of interest to note where the curves in Figure 9 cross the 50% ordinate. These values for observer LAR are 31, 19, and 6 sec. of visual angle for Conditions I, II, and III respectively.

Figure 10 shows data on the median line width which was seen under each of the experimental conditions. Viewing time is plotted on a logarithmic scale. The results are based on sample judgments by the observer. Specifically, the widths of line plotted in the early portion of each curve are those seen in 50% of the short exposures, the durations of which are plotted on the abscissa. The later portion of each curve (i. e., beyond the dashed line) is based on a sampling procedure such that the line of the designated width was seen in 50% of the samples taken at any given time after viewing began. While it is evident from Fig. 10 that Condition III is the best condition for prolonged viewing, one cannot make the simple statement that "acuity" is best under this condition. Prolonged seeing involves both acuity and freedom from local adaptation effects.

Conclusions

1. For very brief exposures of the test object, eye movements can have little or no effect on acuity.
2. For exposures of between .03 and 0.2 sec., eye movements are bad for acuity. This is the case when the observer has but a "single look" at the test object, and the eye movements are typically from 8 to 60 sec. in amplitude.
3. For prolonged viewing, eye movements carry the retinal image over many receptor units, and are increasingly effective in preventing the "washing out" of the visual field due to local adaptation effects. Here, the movements typically amount to 3 minutes of arc or more in amplitude. These larger eye movements are of unquestioned value in the maintenance of prolonged vision. One should not conclude, however, that they improve "acuity" as such. Very fine lines were occasionally seen under all the conditions of these experiments.
4. In no experiment to date have the smallest eye movements (e. g., those involved in tremor or physiological nystagmus) appeared to be of any value in improving visual acuity. With short exposures the tremor movements appear to have a slightly deleterious effect.
5. Experiments now in progress are designed to vary systematically the extent of motion of the image on the retina. The results are expected to yield additional information on the value of eye movements in the prolonged viewing of a stationary target.
6. In most situations of military importance, the normal movements of the eye, head, optical instruments, etc., are sufficiently large to prevent the disappearance or washing out of the visual field.
7. In special situations, such as the prolonged observation of one critical area of the

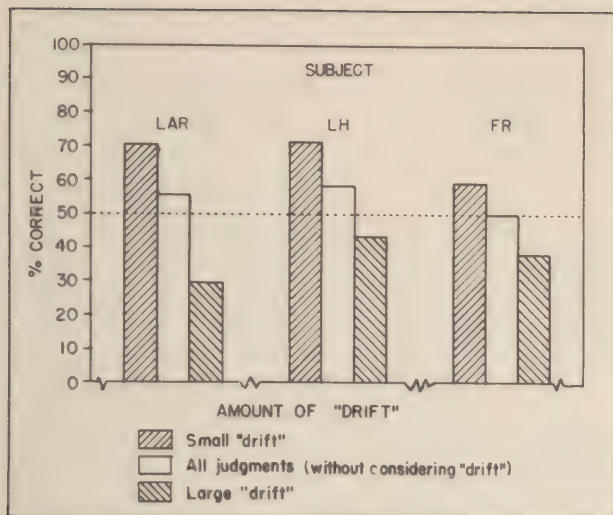


Figure 6. The influence of "drifting" eye movements on visual acuity for a grating test object.

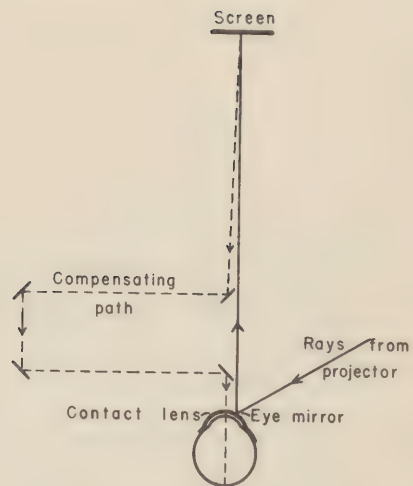


Figure 7. Arrangement for "stopping" the motion of the retinal image.

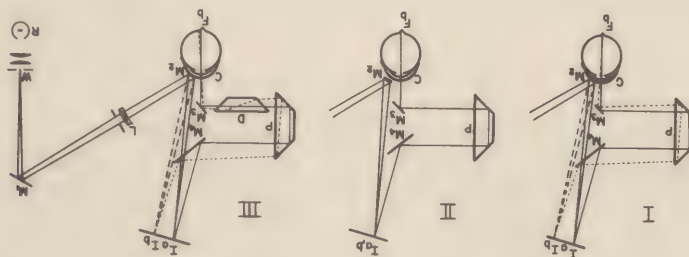


Figure 8. Optical arrangements for varying the effects of eye movements. I. Effects are counteracted. II. Effects are normal. III. Effects are exaggerated (2X normal).

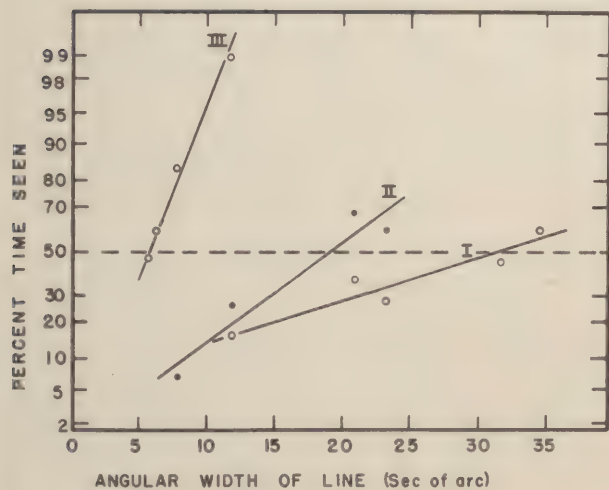


Figure 9. Percentage of time a given line is seen over a one-minute viewing period.

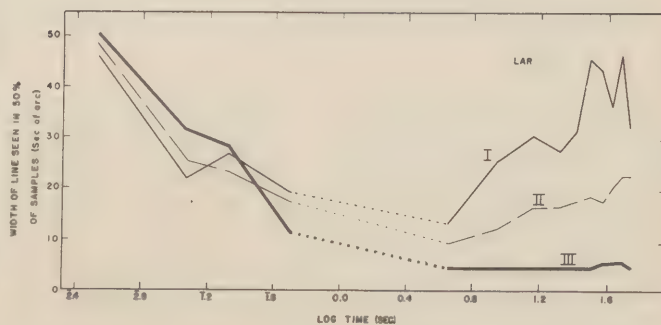


Figure 10. Width of line seen in 50% of samples under each experimental condition.

A STUDY OF WHITE LIGHT "PHOTOSENSITIZATION"***

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The present study was undertaken as a result of the interesting report of "photosensitization" made by Crozier before the 27th Meeting of the Vision Committee. Crozier measured the threshold ΔI for a small target presented for a brief duration on a large background field. The value of ΔI was determined for a number of values of I , the intensity of the background field. Values of I included "zero." Crozier found that the minimum value of ΔI was not obtained for I equal to "zero." This effect was termed "photosensitization."

At the time Crozier made his report, one of us reported that preliminary data obtained with both I and ΔI composed of white light had failed to show the "photosensitization" effect. Professor Crozier commented that "photosensitization" would not necessarily be expected for all experimental conditions, and noted that he had not investigated cases in which I and ΔI were composed of white light.

The present study represents a more complete study of the possible existence of white light "photosensitization." We have obtained confirmation of the conclusions based upon preliminary data that such an effect does not exist.

Procedures

The basic experimental procedures of this study were the same as those used in the study reported by Blackwell and McCready elsewhere in these Minutes. It will be necessary, therefore, to describe only those procedures used in the present study which differ from the procedures employed in the Blackwell and McCready study.

In the Blackwell and McCready study, values of threshold ΔB , the target luminance increment, were determined as a function of B , the background luminance. Precisely such values are required for evaluating the possibility of "photosensitization." In the other study, few experimental determinations were made for small values of B , whereas in the present study, comparatively many experimental determinations have been made for small B . Hence, these data alone are useful in evaluating "photosensitization."

The present study has been restricted to fewer values of the variables, target size and target duration. All measurements have been made with a target duration of 1/100 second. Two circular targets have been employed, with diameters subtending 1 and 45 minutes. There appears at present to be no reason to expect that a "photosensitization" effect would fail to appear under these experimental conditions, and appear when other values of these two experimental variables are used.

In order to eliminate extraneous effects due to the influence of pupillary changes as a function of background luminance, an artificial pupil was employed, consisting of a hole in a metal plate located as near as possible to the cornea. Monocular vision was used. Observers were required to position their eyes accurately with respect to the artificial pupil; this was accomplished by having the observers use a biting board bearing a dental impression. A circular artificial pupil was used with a diameter of 1 mm. This pupil was selected to yield uniform retinal illumination in the vicinity of the image of the target. (It has been found that an artificial pupil of the sort here used produces a pattern of non-uniform retinal illumination from an extended field of uniform luminance, due presumably to the spherical aberration of the eye lens.

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** This research utilized apparatus developed under Project NR142-106; Contract N5ori-116, Task Order V between the Office of Naval Research and the University of Michigan.

Care was taken to insure that dynamic refractive errors did not exist. Each observer made stigmatoscopic determinations of dynamic refraction under the exact conditions of threshold measurement. Corrective lenses were introduced until the resulting errors were negligible. Refractive determinations were made for both high and low background luminances, and they were found to be identical. (This result is of some interest in connection with the problem of night myopia. In our experiment, foveal vision was used at both luminances, the observers were given stimuli to accommodation, and an artificial pupil was employed. Thus, effects due to the Purkinje effect or due to the effects of spherical aberration would not be included.)

Four observers were employed. During some measurements, these observers worked singly; during others, they observed together.

Measurements were made in the cube referred to in the Blackwell and McCready report. The luminance of the cube screen was varied over nine orders of magnitude, not counting "zero" luminance. The greatest experimental problem was the production and photometry of the wide range of background luminances.

The values of luminance from .1 to 1000 foot-Lamberts were produced by different numbers and wattages of incandescent lamps. Photometry of the screen luminances was performed directly with a Macbeth Illuminometer. Luminances below .1 foot-Lamberts were produced by special diffuse luminaires, which were used to illuminate portions of the cube remote from the screen. Thus, the illumination of the screen was all indirect and was considerably attenuated by inter-reflection losses. The luminance of the screen was reduced by introducing Wratten neutral gelatine filters into the diffuse luminaires. The emission properties of the luminaires were unaffected by the addition of the absorbing filters. Hence, the screen luminance bore a constant relation to the luminance of the emitting area of the diffuse luminaires. This relation was carefully measured with the luminaires adjusted for maximum output. The luminance of the emitting area of the luminaires was always great enough to be measured directly. These measurements were compared with independent measurements of the transmission of the absorbing filters, and the two types of measurement were found to be in good agreement. The luminance of the screen could be computed from measurements of the luminance of the luminaire and the factor previously shown to relate luminaire luminance to screen luminance. All photometric measurements were made under photopic conditions, so that luminance measurements are expressed in photopic units throughout.

The fixation and orientation lights were projected onto the cube screen when high screen luminances were employed. For very low luminances, this procedure had to be abandoned since the fixation lights lighted the screen to an appreciable extent by inter-reflections within the cube. In these cases, fixation lights were introduced optically by a partially reflecting mirror located just anterior to the artificial pupil.

The experimental data consisted of values of the target luminance increment, ΔB , and proportions of forced-choice detections. The data were analyzed by the probit analysis.

Results

Our interest here is in values of $\overline{\Delta B}$, the threshold ΔB , at each of a number of values of B . (The threshold is defined by 50% forced-choice detections, correction having been made for chance successes.) Values of $\overline{\Delta B}$ as a function of B are presented in Figures 1-8. Figures 1-4 represent data for the four observers for the target with an angular diameter of 1 minute. Figures 5-8 represent data for the same observers for the target with an angular diameter of 45 minutes. Each experimental point represents a threshold based upon 250 target presentations. (In the figures the experimental point plotted at $\log B = -\infty$ represents a background of "zero" luminance, that is, of no measurable light.)

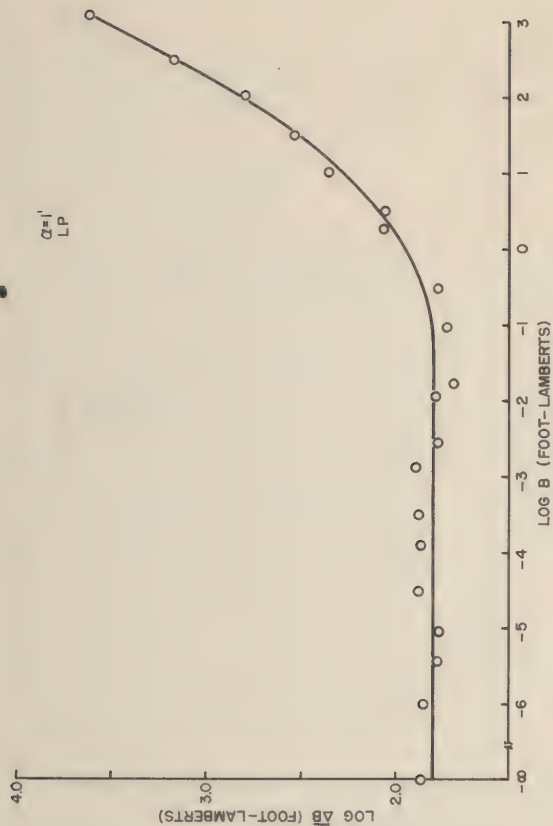


Figure 2. Threshold measurements for observer LP with a 1-minute circular target.

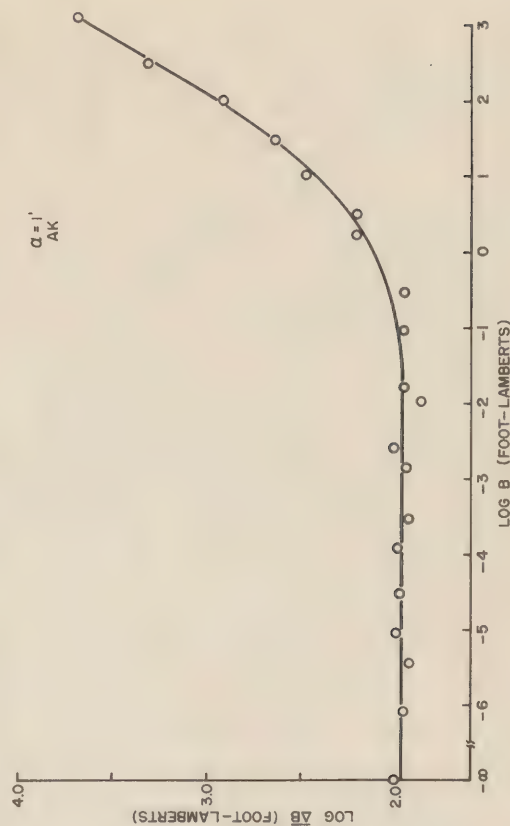


Figure 4. Threshold measurements for observer AK with a 1-minute circular target.

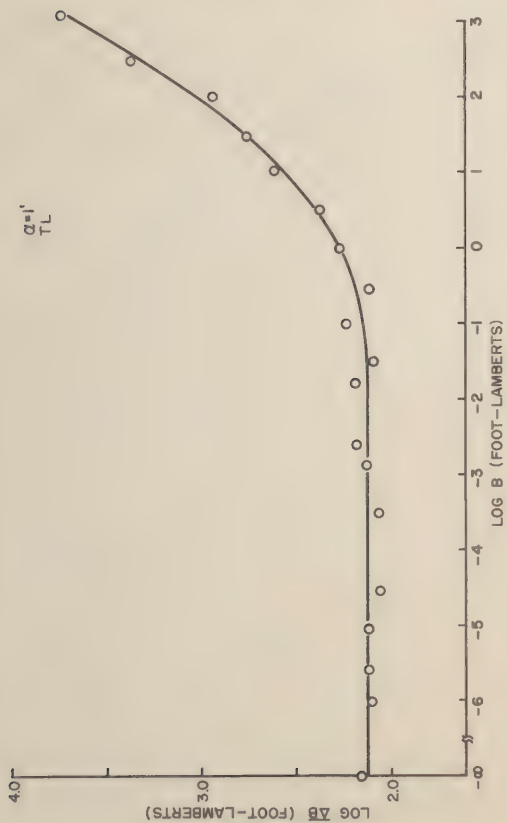


Figure 1. Threshold measurements for observer TL with a 1-minute circular target.

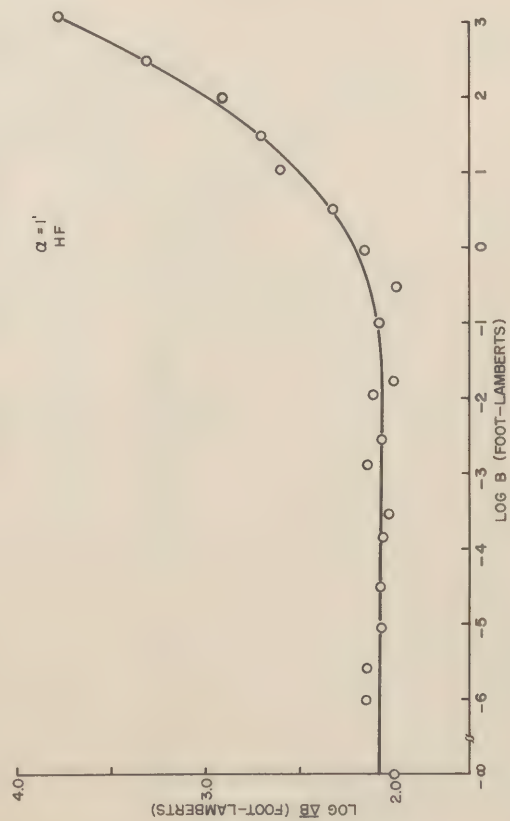


Figure 3. Threshold measurements for observer HF with a 1-minute circular target.

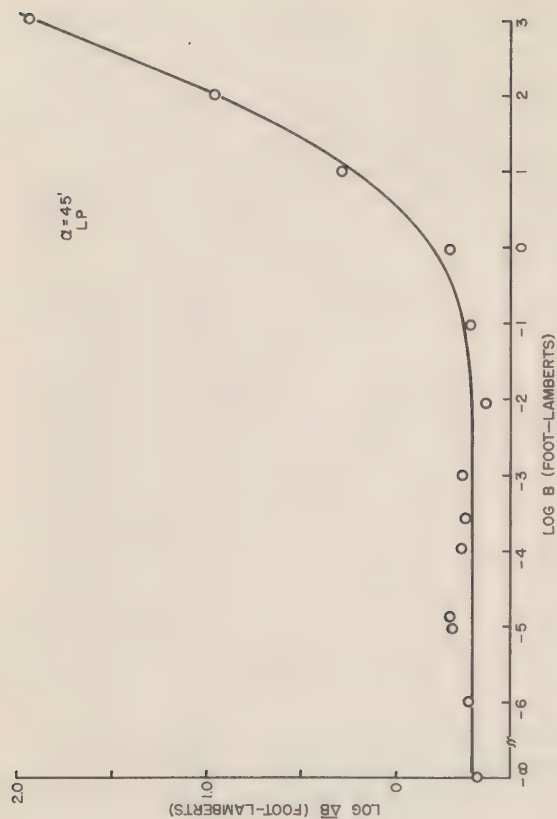


Figure 6. Threshold measurements for observer LP with a 45-minute circular target.

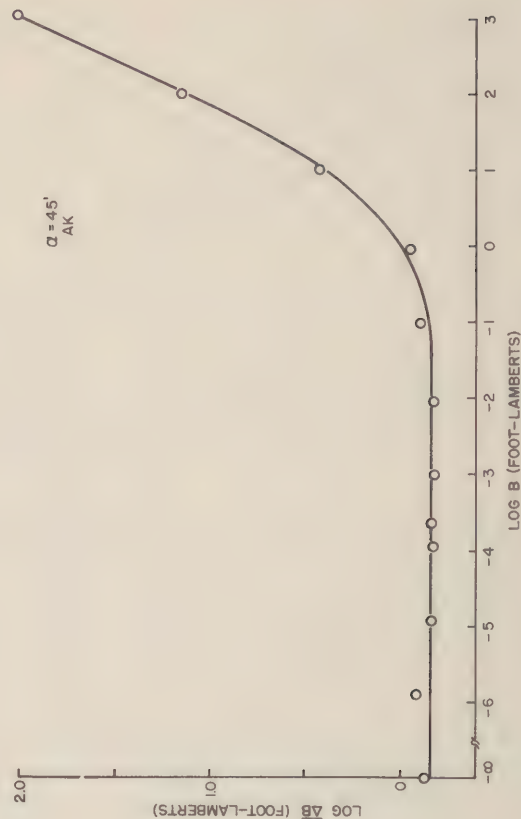


Figure 8. Threshold measurements for observer AK with a 45-minute circular target.

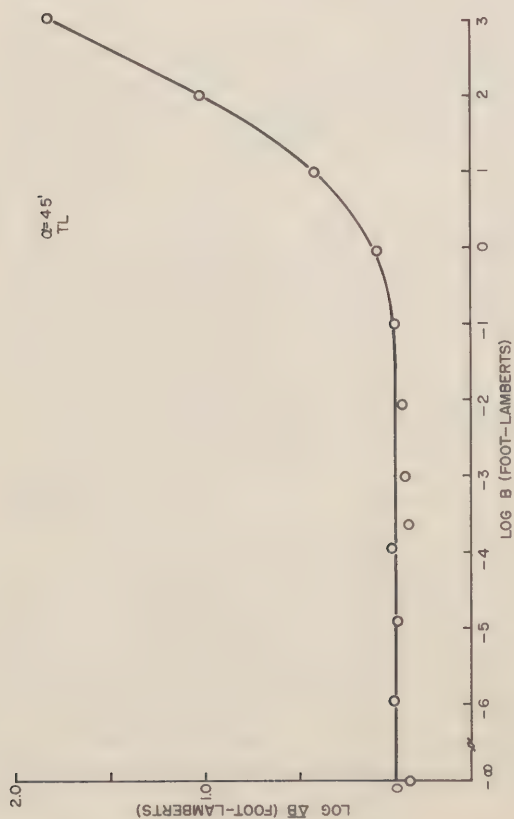


Figure 5. Threshold measurements for observer TL with a 45-minute circular target



Figure 7. Threshold measurements for observer HF with a 45-minute circular target.

visual field, it might be desirable to introduce deliberately an occasional momentary shift in the visual field to overcome local adaptation.

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ON INCREMENTAL VISUAL INTENSITY THRESHOLDS

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Harvard Biological Laboratories

It has been proposed (Stiles, 1939; 1946a, b; 1949) that the curve relating the 'smallest' foveally perceptible intensity of a briefly exposed (blue, for example) small image at the center of a much larger adapting (e.g., orange) field I_1 steadily present, exhibits a characteristic division into 2 (or even 3) components as the intensity of the adapting field is raised in steps. A process was worked out by Stiles (1939, 1946a, 1949) for deducing from such data the basic excitability contours for three primary, separable color functions: a blue, a green, and a red. In the specific case mentioned (from Stiles, 1946b) it was supposed that the blue stimulus acted at first over the range of intensive receptivity of a green mechanism, at higher intensities of the orange adapting background on a "blue" component mechanism. It is essential to the theoretic use of this conception that the "green" and "blue" receptive mechanisms, as in the example, do not serve additively but are activated solely by virtue of their independent excitability functions.

From a quite different starting point I have been led into a rather elaborate examination of the results obtainable in experimental situations essentially duplicating those giving rise to data of the type which Stiles has utilized. The conclusions are very different from those which he has advanced. The reasons for this turn out to be easily assignable. They are of considerable methodological significance. It is in fact not the case, foveally, for any of the λ -combinations Stiles has discussed, that the "heterochromatic ΔI " shows a dependence on I_1 which is broken into segments.

Experiments of this type are capable of extensive elaboration. By direct examination of the properties of ΔI as $f(I_1)$ one escapes the historically derived fascination with $\Delta I/I_1$ as an essential index, and one is enabled to include naturally the important "absolute" threshold case, when $I_1 = 0$. The relevant question is, By what procedure is " ΔI " to be estimated? A varied experience over the past 5 years makes it very clear that the revealing method involves determinations of "seeing -frequency" functions ($\psi[S]$), with adequate numbers of presentations.

The tests here considered arose not in any definite relation to Stiles' reports, but in quite another connection. With small images at the fovea it was found, and systematically supported by much later work, that $\psi(S)$ can be regarded as a log-Gaussian integral, for not ultra-brief exposures. A theoretic basis for this can be provided, but is of no concern at the moment. This function has 2 parameters: σ , the S.D. of the distribution, and λ' its mean. The third parameter, the asymptotic maximum, is 100 per cent. in the nature of the experiment. The 2 visible parameters are demonstrably changeable, independently, according to conditions imposed. At the dark-adapted fovea, σ is a periodic function of λ . For the dark-adapted retinal periphery there is no λ -periodicity of σ , and the picture as a whole is very different. At the fovea, the determination of $\psi(S)$ as a function of λ under conditions of high and of low O_2 -intake in respiration has specifically supported the particular type of photosensitization earlier suggested. A further test of the general situation involved examination of homochromatic and heterochromatic ΔI 's by the process of flashing a brief, small image of λ_2 upon the center of a large field (λ_1) to which adaptation has been established. This is the manageable form of the historical "differential exhaustion" experiment in the search for λ -primaries. It involved establishment of $\psi(S)$ for stepped intensities of the adapting λ_1 , by procedure already outlined, for a large number of $\lambda_1 - \lambda_2$ combinations.

There are definitely indicated in the results phenomena of λ - "interaction", and their properties can to a degree be specified. Among them is a kind of cross-photosensitization as between effects of different λ 's, which we were made to recognize some years ago in experiments of a very different sort. These effects are of only subsidiary interest here, although they hold the possibility of considerable analytical interest. In the cases here illustrated the sensitization effect is small.

But there is nowhere in these voluminous data any trace, at first sight, of the phenomena which Stiles' papers have recorded. The curve of $\log \Delta I_{50}$ vs. $\log I_1$ is smooth, rising to a limiting slope of 1 or above. It exhibits no division into segments, no matter what the λ 's of background and of test-flash.

I take two cases, from among a number available, within the zone of contrasting λ_1 and λ_2 , for adapting background and for test-patch respectively, which Stiles has designated as producing the most pronounced cusps in curves of $\log \Delta I$ vs. $\log I_1$, midway in the course of the usable range of I_1 . The conditions were, in example 1: 0.50° square test patch (λ_2) foveally centered; 15° square adapting field (λ_1); test-patch exposure 0.051 sec; λ control by interference filters with masking filters, band half-widths ca. 12 m μ . These conditions fall well within the zone where, by Stiles' graphs, a maximum differential effect should be exhibited. The observer (unicular) is an experienced one (LHC), and by every test is color-normal. The curve in Fig. 1* shows that there is no division into 2 segments. (With correction for differences in intensity units, it is clear that Stiles' intensive range has been covered).

The central point concerns the mode of estimation of $\Delta \bar{I}$: In Fig. 1 $\log \Delta I$ is the median, λ' as obtained from seeing-frequency data ($\psi[S]$). In 1939 Stiles made it clear that he appreciated the analytical significance of this laborious procedure, and gave an illustration of its use, with white light. At the fovea, a non-cusped curve in the coordinates of Fig. 1 was obtained.

So far as one can gather, the majority at least of the subsequent data used by Stiles was obtained by a different process. This involved the observer's adjustment of a changeable, flashed, intensity until, after a relatively few trials, "the threshold" was decided. There is a remarkably significant difference between the properties of λ' and of a " $\Delta \bar{I}$ " arrived at by this latter process. The difference is intimately related in origin to the empirically established properties of $\psi(S)$.

Leaving aside consideration of the phenomena of photosensitization--which concretely can produce, as function of the adapting λ and its (low) intensity, lowering of $\Delta \bar{I}$ as respects its value with a no-light background--there is a general pattern in the behavior of σ and of λ' for $\psi(S)$ as the intensity of the adapted-to background is increased. In the large, and to a theoretically surprising degree, in terms of some customary conceptions, λ' does not change very much over a wide zone of $\log I_1$. For still higher background $\log I_1$'s, it rises smoothly to a limiting slope of 1.

From Stiles' papers containing the records concerned it appears that curves of this type were obtained when, using 'white' light, there was reliance on a $\psi(S)$ procedure. It is strange that it was not noted in the data of the single minute published figure, one of the earliest parametric analysis tests of this sort, that $\sigma_{\log \Delta I}$ in general decreased as the I_1 was elevated. A point is that attention might well have been suggested to the behavior of $\sigma_{\log \Delta I}$ with I_1 changed.

There is in fact here the key to resolution of the apparently flat contradiction already noted as between the results I have illustrated and those which Stiles has utilized. For

*The six figures referred to in this paper were not available for reproduction in the minutes.

reasons which can be proposed, but at any rate in fact, σ changes systematically as a function of dominant λ of the adapting field, and also of its intensity. For certain $\lambda_1 - \lambda_2$ combinations low intensities of background produce a real photosensitization, so that the mean ΔI is lower than with zero background. In these cases $\sigma_{\log \Delta I}$ increases. As background I_1 is made greater and greater, σ becomes at first progressively smaller, but increases rather markedly when the background is intense enough to produce about 60 per cent. loss of the maximum stimulating efficiency of the test-light; with still higher background intensities, $\sigma_{\log \Delta I}$ decreases sharply.

Accepting the maximum value of $1/\Delta I_{\min.}$, the ΔI_{50} quantities for ascending series of background intensities provide the "reverse" of the customary picture of dark-adaptation. What is exhibited is the influence of background intensity in progressively reducing the maximum excitability for the test- λ ; $1/\Delta I_{50}$ is a declining Gaussian integral in $\log I_1$. The parameters of this function give specific indices for the interactions between the components of various λ -pairs. To a considerable extent these interactions have been mapped out.

From Fig. 2 it is apparent that if a procedural operation for obtaining an estimate of "the" incremental threshold is by its very nature such as to yield a ΔI which does not agree with ΔI_{50} as obtained from $\psi(S)$, the data in such a case as that used in Fig. 1 cannot give the smooth, uninked function provided by ΔI_{50} . From the data of Figs. 1 and 2 it is easy to obtain the ΔI values for, say, the 95 per cent. frequency of seeing. They are shown in Fig. 4. A division of the curve into two branches is then apparent, just as in Stiles' graphs. It seems highly probable that the "method of adjustments" with brief exposures of fluctuating test-intensities, used by Stiles, inevitably gives mean values of intensity "thresholds" acceptable to the observer which correspond to a seeing-frequency well above the 50 per cent. point. In fact, we have a direct test of this to be considered in a moment. Recall that in the use of a $\psi(S)$ procedure Stiles did not find a duplex curve.

On the other hand, it is equally to be expected that by using a method with steps of increasing intensity, mean thresholds lower than ΔI_{50} would form a contour with a singular region bent in the opposite direction (with the cusp at a lower I_1). For illustration, in Fig. 4 the threshold intensities corresponding to 5 per cent. seeing-frequency have been plotted also.

No explanation is attempted in this condensed note for the increase of $\sigma_{\log \Delta I}$ at around 60 per cent. or greater decrease of maximum excitability. For one observer there was coincidence with achievement of background intensities for which the adapted experience held the beginnings of color. For another, not quite color-normal, with a very much smaller foveal achromatic interval, there was no such correlation. It is still possible that in this zone there occurs a 'change of discriminatory criterion,' induced by a change in the sensory impress of the adapting background. This cannot be a very fundamental effect, for ΔI_{50} shows no discontinuity. It must be concerned with the distribution of the chances of discriminatory seeing; it is not specifically involving color, since it also occurs with 'white' light.

Implicit in this general argument is the prediction that if similar changes in $\sigma_{\log \Delta I}$ as function of I_1 occur in the use of 'white' light test patches flashed on standing 'white' backgrounds, and they do, it should be possible to obtain foveal duplex incremental threshold curves with 'white' by use of the adjustments process. In fact, this result has been found.

The sequence of changes in $\sigma_{\log \Delta I}$ as the adapting intensity I_1 of the background is raised is overall one in which $\sigma_{\log \Delta I}$ declines as I_1 increases. This is quite consistent with the notion that σ measures, under certain conditions, the relative size of the available population of not-adapted-out and thus potentially excitable elements of sensory

effect. Note also that as raising I_1 increasingly adapts-out elements of sensory effect one does not deal with truncated $\psi(S)$ distributions. In fact one deals with reduced distributions of the same analytical form. No system of interpretation of the properties of visual excitation data grounded on or implicitly accepting a theory of static distribution of individual receptor thresholds can possibly cope with this fact.

The extent to which $\sigma_{\log \Delta I}$ is raised in the neighborhood of 60 per cent. -loss of dark-adapted excitability $\sigma_{\log \Delta I}$ varies considerably with the $\lambda_1 - \lambda_2$ situation. We have chosen for illustrative use here cases within the range of those found by Stiles to give the most pronounced effects under the conditions of his tests. (A number of the broken interpretive curves offered by Stiles as indicating duplex excitation functions are scarcely acceptable as descriptions of the data recorded.)

A direct test of this conception was made by running two series of experiments with the same $\lambda_1 - \lambda_2$ combination. In one set, $\psi(S)$ was determined with each background intensity. In the second series mean ΔI was obtained by the observer's adjustment of flash intensities. The results are summarized in Fig. 5. The parallel with the effects predicted from Fig. 3 is striking, and confirmative.

I am consequently unable to accept Stiles' argument based on the evidence provided for the demonstration of separably excitable color-fundamentals as being revealed by data of heterochromatic incremental intensity thresholds. The analogy drawn from the duplex character of contours emerging from parafoveal tests of this kind is illusory. The basic 'finding' was apparently an artifact arising from the nature of the procedure Stiles used. Incidentally, facts such as those illustrated here, and now available in considerable number, argue powerfully for the use of ΔI as a natural, valid parameter of $\psi(S)$. They also argue for the interpretive value of $\sigma_{\log \Delta I}$ the σ of $\psi(S)$.

With heterochromatic, as with homochromatic incremental threshold tests made outside the fovea, one obtains, as did Stiles, duplex threshold contours reflecting the scotopic-photopic functions. One such set is used in illustration here. 'White' light is used for the $(0^{.5})$ test-image at 10^0 temporal, in one case with $\lambda 461$ as adapting background and in another with $\lambda 696$ (Fig. 6). Analysis shows that for the scotopic and for the photopic branch the changes of σ are similar to those at the fovea. There is also indication of (slight) changes in the zone of photopic-scotopic overlap, not unexpected. In this region of overlap the actual course of the (mean) data is below that for computed summation of the separate rod and cone excitabilities.

For the blue background there is indication of a slight lowering of the "final" low-end threshold, as shown by the log-Gaussian fit to this branch. With the red background there is none.

Note, however, that the form constants for the blue "rod" branch and for the red curve are nearly the same. If the blue and red abscissa intensity scales are adjusted to be in "sensation units" (multiples of "absolute" threshold) the blue "rod" branch and the red curve coincide. There is thus ground for holding that the presence of the red serves to 'adapt out' rod functioning. If the red-background data represent cone functioning, then the red has sensitized parafoveal cones. The former alternative is preferable, but opens up some interesting possibilities.

The main reason for introducing Fig. 6 is to bring to mind the point curiously omitted by Stiles: In no case does the presumptively "cone" curve for heterochromatic parafoveal incremental thresholds exhibit undulation into several branches, even in Stiles' data.

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NIGHT MYOPIA AND PHOTOGRAPHY OF THE PURKINJE IMAGES

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The stimulus for the work that I wish to describe was a rather long-standing disagreement between us, at the Naval Research Laboratory in Washington, and Otero, at the Naval Research Laboratory in Madrid, Spain. This concerns the principal cause of night myopia. I think that just about everyone agrees that night myopia exists to a greater or lesser extent, in many eyes; and that for many people, especially myopes, corrective negative spectacles of, perhaps, 1 diopter to be worn under quite dark conditions, increase their ability to see at night quite significantly.

When it comes to the causes of night myopia, however, there are two schools of thought. Both agree that the chromatic aberration of the eye contributes a little to the total night myopia, but not over 0.5D. However, the one school attributes the rather large remainder, of 0.5 to 1.5 diopters depending on the eye and various conditions, to involuntary accommodation. The other school, which we support, believes that it is caused mainly by the undercorrected spherical aberration of the eye.

We thought that we had disposed of the accommodation theory and proved conclusively that spherical aberration, at least for our eyes, was the principal source of night myopia when we reported to this committee at the Ottawa meeting some experiments in which the eye was maintained accommodated for infinity while night myopia was being measured. The accommodation was controlled by introducing a very small target at low photopic levels into the field of view and requiring that the observer all the while keep this target resolved. At the same time he viewed another target parafoveally. The second target was large and was adjusted to a low brightness and was viewed with scotopic vision. Spectacle lenses of different powers were introduced for the second target and the correction that produced the most acute vision was determined. This was the value of night myopia for the particular brightness level of the target, and was determined in the absence of accommodation. It was essentially the same when determined without using any device for relaxing the accommodation. This work was subsequently published in the Journal of the Optical Society of America and is, in our opinion, definitive.

About the same time, however, Otero made measurements of the state of accommodation by photographing the Purkinje image produced by the anterior surface of the eye lens. This procedure has the advantage of being purely objective. Otero found that the eye under completely dark conditions took on a state of accommodation of 1 or 2 diopters, and offered this as evidence in favor of the accommodation theory of night myopia. This was, of course, contradictory to our findings. I have also received a short report from Dr. Imus when he was at ONR, London, of similar work by Campbell and Primrose, at Glasgow, who reached conclusions about the same as those of Otero. The only thing to do in a case of this sort was to repeat Otero's work with our subjects and see if the results agreed or disagreed with our earlier conclusions.

First, I would like to recall to you how night myopia sets in as the field brightness is decreased. Figure 1 shows the situation as far as four of us are concerned. The field brightness is plotted horizontally, in μL . The best spectacle correction in diopters is plotted vertically. This was determined using a high contrast grating test object. From daytime levels down to approximately the brightness level where rod vision takes over there is almost no night myopia. The best correction for a high brightness is the best correction for all brightnesses in the case of photopic vision. For brightness in the scotopic range, optimum vision calls for increasingly negative lenses, the power being roughly proportional to the logarithm of the brightness. We went on to show how the spherical aberration of the eye was sufficient to account for these facts,

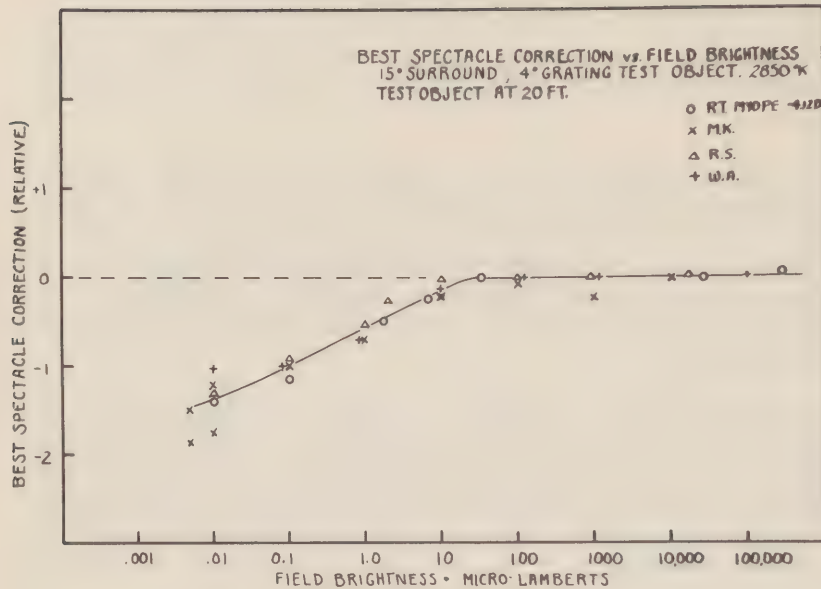


Figure 1. The variation of night myopia with brightness of the scene, for four subjects. The target was a high contrast grating.

then applied their findings to explain night myopia. This cannot logically be done. Night myopia refers to the optimum correction when one is looking at something. Night myopia has no meaning at all, however, when one is in complete darkness. When one is looking at something, even though the brightness is very low, visual stimuli are present to some degree. Certainly the convergence clue to focussing may be present, to some extent, for one does not see double. If one assumes that a diplopia amounting to 1° may exist unnoticed, and I should think this would be about the limit for scotopic vision, and if this convergence stimulated the corresponding accommodation, the power of the accommodation would be only $1/3$ diopter. Thus, it seems to me that convergence must still be of some aid to the proper focussing of the eyes at night. The acuity clue may also be of some aid, at least at the higher scotopic levels, though this is somewhat in doubt. In complete darkness, however, these stimuli no longer exist; the eyes may very well accommodate and converge and take on a condition which would not result in optimum vision were there present some light.

Coming now to Otero's experiment, Figure 2 shows our set up, and it is not significantly different from Otero's, so far as we can

and we actually reproduced this curve from data obtained with a glass lens having spherical aberration similar to that of the eye.

Now the point that I wish to make is that in our experiments the subject was not in complete darkness, but was looking at an illuminated target. To be sure, at the lowest brightness level, about $.01 \mu\text{L}$, there was very little light; in fact, this was just about the very lowest level at which we were able to make acuity measurements, and so to determine the night myopia. On the other hand, Otero, and Campbell and Primrose, have apparently measured the state of accommodation in complete darkness, and



Figure 2. Apparatus for photographing the Purkinje images for various states of accommodation. A, flash lamp covered with a double aperture; B, camera; C, accommodation-fixing test object.

see. There is a 500 μ sec. flash lamp at the left, with a reflector. Over this is placed an opaque diaphragm with two holes, which do not show. Their diameters are 1 cm and they are 6 cm apart. They are brightly illuminated by the flash. The observer's head is placed in the rest and the two circular sources, when flashed on, are imaged in the various surfaces of the right eye. The camera in turn photographs the eye and the several images super-imposed upon the pupil. At the extreme left there is an accommodation fixing target consisting of a small Landolt ring, or grating, and a light. This can be moved toward or away from the eye and serves to cause the eye to accommodate for particular distances. It is used to determine the relation between the separation between the Purkinje images and accommodation, and so to calibrate the experiment.

Figure 3 shows some photographs made with this equipment. There are visible three sets of Purkinje images. The two very large and intense images are produced by the cornea. They are not in focus, for we are not particularly interested in them. The central rather dim pair is produced by the anterior surface of the lens and is termed the second Purkinje image. They are weak because the reflectance at the lens to aqueous interface is small. This is the pair that is of interest. The anterior surface changes curvature in accommodation and therefore their separation depends on the state of accommodation. The camera was focussed on them as well as possible. In some eyes they are diffuse and weak. There is still a third pair, hardly visible here, produced by the posterior surface of the lens. These are of no interest since their separation does not vary except with very strong accommodation.

Figure 3A was made using the accommodation fixing target at substantially infinity. The eye was not dark adapted, and was in an unaccommodated state. Figure 3C is a similar photograph in complete darkness with the eye dark adapted. The result is almost



Figure 3(A).



Figure 3(B).



Figure 3. Photographs of Purkinje images of emmetrope R. S. under various conditions. In Fig. 3(A) the eye was focused for 5 meters (far vision), in 3(B) for 25cm, and in 3(C) the eye was in total darkness.

identical; the separation between the second images is unchanged. Figure 3B, however, shows the images when the eye was focussed for 25 cm, i.e., when there was 4 diopters of accommodation. The second images are much closer, now, and sharper also. Thus, in the case of this observer, there is evidence that there is no accommodation in the rest state in complete darkness.

Figure 4 shows similar photographs for another subject. In his case, the second Purkinje images are particularly large and diffuse and hard to measure accurately. Figure 4A is for the light adapted eye, accommodated for infinity. Figure 4C is for the dark adapted eye in complete darkness and the separation is the same as in 4A, showing that in his case also, the rest state of the eye in complete darkness was unaccommodated. In Figure 4B the images are closer for his eye was looking at the target placed at 50 cm, i.e., the eye was accommodated to 2 diopters.

One of the difficulties of this experiment is that the separation changes quite a little when the eye changes its direction of fixation, even slightly, and the images move to a different location on the pupil. This, in our opinion, may be one of the reasons why others have obtained different results from this experiment. We took great pains to insure that the eye remained fixated in the proper direction. For some experiments this was done with the aid of a very dim source flashed on once every few seconds, and of a nature such as not to offer clues to accommodation. In some cases it was accomplished by taking many photographs in complete darkness and selecting only those which gave centered images. Two other schemes were tried with me, and I do not think they are new. One was to use a dim source that almost filled the blind spot and to require that it fall within the blind spot, that is, that it not be seen. This was very hard for me to use. The other was to use a very dim blue source as a fixation point, adjusted so as to be invisible when on the fovea, and to require that it not be seen. This was easier to use than the blind spot



Figure 4(A).



Figure 4(B).



Figure 4. Photographs of Purkinje images of emmetrope M. K., who had particularly diffuse images. In Fig. 4(A) the eye was focused for 5 meters (far vision), in 4(B) for 50 cm, and in 4(C) the eye was in total darkness.

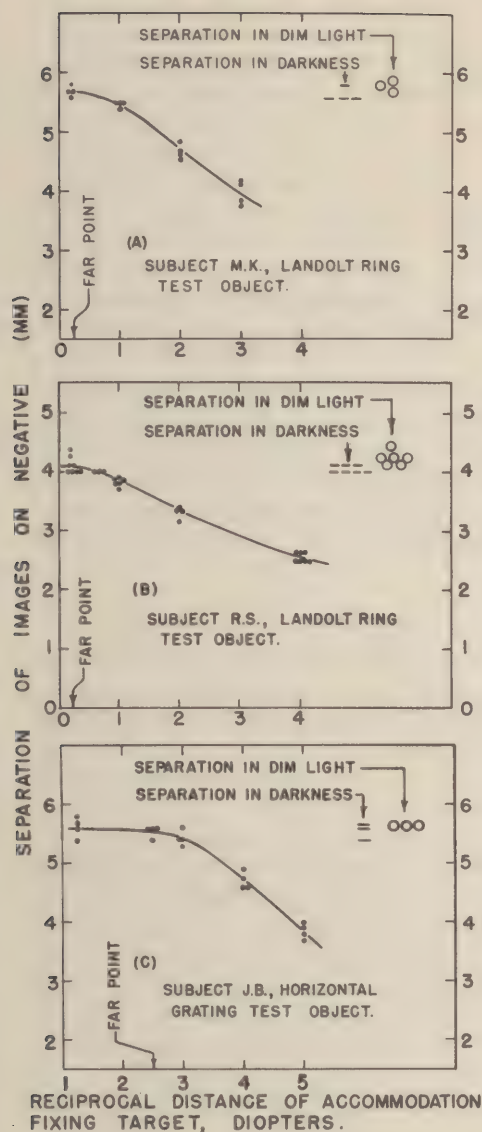


Figure 5. Separation of the second Purkinje images of a double aperture, plotted as a function of the state of accommodation. Graphs A and B are for nearly emmetropic subjects; C is for a low myope. To the right of each graph are plotted the image separations when the eye viewed a distant dimly illuminated scene and when the eye was in complete darkness. In the two latter cases there was no attempt to fix the subject's state of accommodation.

which was his far point. This subject, also, showed no evidence of accommodation in dim light or in darkness.

In my own case, the results in dim light were similar to those you have seen and show that I did not accommodate under the conditions when I exhibit night myopia.

The conclusion of this is that Purkinje image photography supports our previous conclusion, that night myopia is not due to accommodation, but to spherical aberration, supplemented, of course, by chromatic aberration.

technique. Both methods were quite a strain and seemed to stimulate accommodation.

Coming now to more quantitative results, the separation between the images was measured as a function of the accommodation, by requiring the observer to resolve the pattern of the moveable target. Typical results are shown in Figure 5. Plotted here is the measured separation between the second Purkinje images, versus the reciprocal distance to the accommodation fixing target, that is, the diopters of accommodation. The separate points refer to individual exposures.

In Figure 5B, for Mr. Scolnik, one diopter of accommodation changes the separation from 4.1 mm to 3.8 mm, not a great deal, but enough to serve as a rough index of accommodation. Were the images sharper, the method would be more exact. The next step was to become dark adapted and to take photographs of the images in complete darkness, and also with the room lighted to about the level where maximum night myopia is present. The results for this observer are shown on the right of the figure. The dim light exposures scatter through 2 or 3 tenths mm, but all fall within the range of values covered by the points taken with the accommodation fixing target located at the far point. This is taken as proving that this eye, under dim light conditions, did not accommodate, and therefore that the night myopia known to exist for this eye was not due to accommodation. In complete darkness the points fell in practically the same range. Here again there is no evidence that the observer was accommodating.

Similar results were obtained with Mr. Koomen's right eye, as shown in Figure 5A. As shown in Figure 4, his images were quite diffuse and hard to measure. Their separation varied with accommodation about twice as rapidly as it did for Mr. Scolnik. The points at the right show that neither under dim light conditions where he exhibited night myopia, nor in complete darkness, did he accommodate.

Figure 5C shows data for a third individual. This subject was untrained and was a 2.5 diopter myope. This is why the curve becomes horizontal to the left of 2.5,

One wonders then why Otero's results seem to conflict with this. I am not sure that they do. In the first place, he states that the Purkinje image photographs were obtained in complete darkness. As I explained earlier, there is no visual stimulus to prevent accommodation if there is nothing to see. Under these conditions it is quite likely that some subjects do accommodate. In fact, I am such a subject. Although my Purkinje photographs showed no accommodation in dim light, I gave variable results in complete darkness, and exhibited accommodation on one occasion as high as 1.5D. When in dim light, however, where I know that I have considerable night myopia, the accommodation vanished.

Returning to Otero, I believe that the cases he cites may be similar to mine. I do not object to the result, but only to his interpretation, that the accommodation found in complete darkness accounts for their night myopia.

I do not wish to go further into the matter of accommodation in complete darkness, for we have practically no data on this. Furthermore, I am not sure that it is particularly important in problems of night vision, for there is always a little light outdoors at night. I might say, however, that in my case the accommodation exhibited in complete darkness seemed to be related to the effort that I was making to look in the correct direction so that the Purkinje images would be centered when the flash came.

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EFFECT OF FLASHES OF LIGHT ON NIGHT VISUAL ACUITY

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INTRODUCTION

The ultimate objective of this study is to discover a satisfactory method of predicting the course of constriction of the pupil of a dark adapted eye when exposed to a flash of any duration or a series of flashes involving a complex and changing distribution of brightness in the visual field. This problem is quite complicated for several reasons. It involves the differential distribution of rods and cones over the retina with their independently varying states of adaptation and speeds of reaction. It involves the distribution of ganglion cells and their connections through the bipolars with the rods and cones. It involves the mechanism in the midbrain for summing the impulses received simultaneously from various areas of the retina and also the mechanism for summing impulses spread out in time; and it also involves the response of the sphincter muscle of the iris to the pattern of impulses relayed to it by the ciliary ganglion from the Edinger-Westphal nucleus.

Finally, the role played by stray light has to be taken into consideration and this is particularly important in the case of a bright patch subtending a small solid angle, and having a dark background. The small number of photoreceptors stimulated directly by the bright patch might well have a negligible effect upon pupil constriction in comparison with the effect produced by the thousands of photoreceptors which are stimulated only by the stray light in the eye.

One can analyze this aspect of the problem further by assuming that the effect of stray light in the eye can be computed from the Stiles-Holladay formula,^{1, 2, 3, 4} according to which the retinal illuminance dI_V at a given point P' on the retina, produced by a bright patch subtending a small solid angle $d\omega$ and displaced at an angle θ from the line of sight OP which corresponds to the point P' on the retina, is given by the following equation:

$$dI_V = \frac{10 BA}{(57.3)^2} \left[\frac{2 \mu \sin \theta \cos \theta}{\theta^2} \right] d\omega \quad (1)$$

provided θ is expressed in radians and is larger than 0.035. A is the area of the artificial pupil in mm^2 . B is the brightness of the patch in c/m^2 . μ is the angular displacement of the patch from the pupillary axis. I_V is measured in trolands and ω in steradians.

In the experiments described in this report the beams of light entering the eye are restricted by artificial pupils normal to the axes of the beams, and since the circular patches exposed to the eye did not exceed 8° in diameter, it is satisfactory to assume that $\cos \psi = 1$.

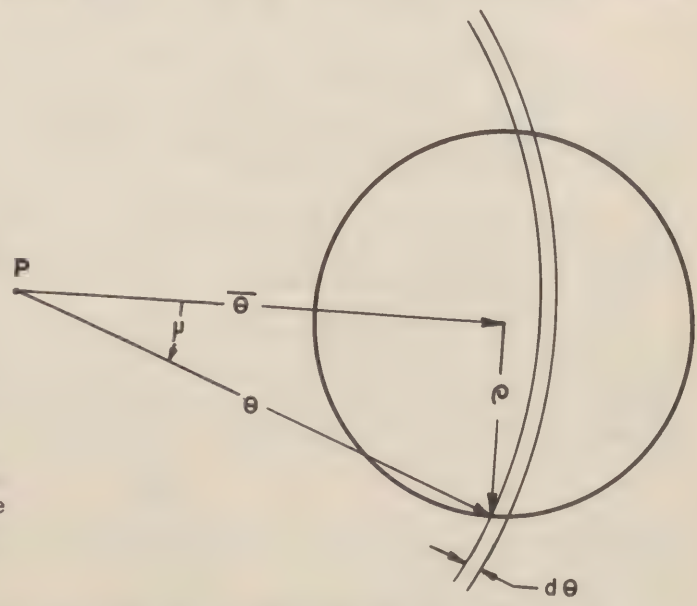


Figure 1. Method of Integrating the Stray Light Produced by the Different Zones of a Bright Patch.

From Eq. (1) it is possible to derive an equation for computing the illuminance I_V at P' on the retina produced by a circular patch, the center of which is at an angle θ from the line of sight OP . The circular patch is divided into zones concentric with P as shown in Fig. 1.

$$I_V = \frac{20 BA}{57.3^2} \int_{\bar{\theta}-\epsilon}^{\bar{\theta}+\epsilon} \frac{\mu \sin \theta}{\theta^2} d\theta \quad (2)$$

where

$$\cos \mu = \frac{\cos \epsilon - \cos \theta \cos \bar{\theta}}{\sin \theta \sin \bar{\theta}} \quad (3)$$

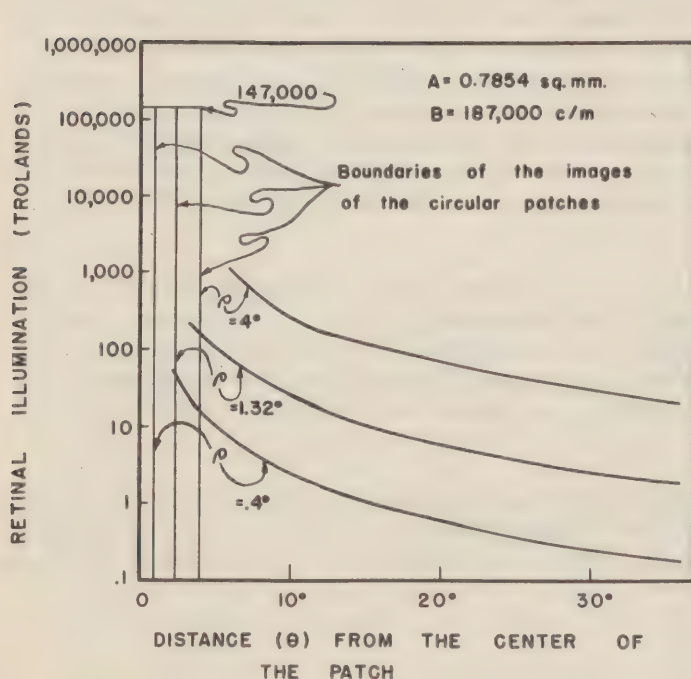


Figure 2. The Effect of Increasing the Size of a Circular Patch Upon the Distribution of Retinal Illuminance Outside the Retinal Image of the Patch Produced by Stray Light.

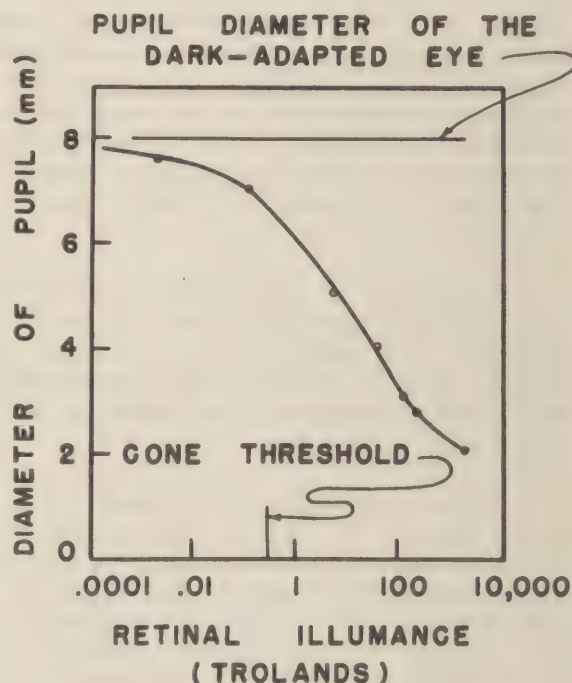


Figure 3. Reeves Data for Pupil Size as a Function of the Retinal Illuminance Produced by a Surface Subtending Nearly the Whole Field of View.

Values of I_V have been computed as a function of $\bar{\theta}$ for circular patches subtending 0.8° , 2.64° and 8° . These patches subtend solid angles equal to 0.000154, 0.00154 and 0.0154 steradians respectively.

Since Eq. (1) does not hold for values of θ less than 2° (0.035 radian), values of I_V have not been calculated for values of $\bar{\theta}$ less than $(\epsilon + 2^\circ)$. The distributions are shown in Fig. 2 along with the distributions of retinal illuminance (I) in the images of the patches focused on the retina, calculated in accordance with the equation,

$$I = BA \quad (4)$$

where B is the brightness of the patch in c/m^2 and A is the area of the pupil in mm^2 .

Hess⁵ has called attention to the role played by stray light by demonstrating that a pupil response is still obtained when the patch of brightness producing the response is placed in the blind spot.

Reeves⁶ used a uniform distribution of brightness covering the entire visual field and

and measured the pupil size after the eye had become adapted to various brightness levels and after the pupil had reached a reasonably steady state. His averaged data for 6 subjects have been replotted in Fig. 3, which shows pupil size as a function of retinal illuminance. Equation (4) has been used in computing retinal illuminance. No allowance has been made for the Stiles-Crawford effect or the obliquity of the plane of the pupil. The pupil evidently responds to levels of retinal illuminance lower than the threshold for the cones⁷, but the measurements were limited to too few brightness steps to determine whether there is a break or modulation in the curve to indicate when the cones come into play.

Various investigators have found a Purkinje shift⁸ in the pupillomotor response, which is another way of demonstrating the transition from rod to cone vision.

Effects depending on the state of adaptation⁸ have also been investigated.

Furthermore, a pupil response to rods can be demonstrated in the case of persons with total color blindness who have a scotopic luminosity curve.⁸

De Launey has used a spot 2° in diameter located at the center of the fovea and a similar spot located in the periphery to determine the extent of pupil constriction produced by various brightnesses. De Launey claimed that since no pupil response was obtained in either case until after the threshold level of the cones was reached, the pupil responses obtained depended entirely upon the stimulation of the cones.

As will be shown in this report, the response which he found must have been a response to stray light outside the image of the spot. That the threshold of the pupil response coincided with the threshold of cone vision must be a coincidence because the threshold of the pupil response can be varied by changing the area of the patch of brightness. What probably determines the threshold in this case is the threshold of the rods in the periphery of the retina which are stimulated by stray light.

APPARATUS

Fig. 4 represents a horizontal section through the center of the entrance pupil of the eye E. The right eye of the subject is controlled by means of a biting board and forehead

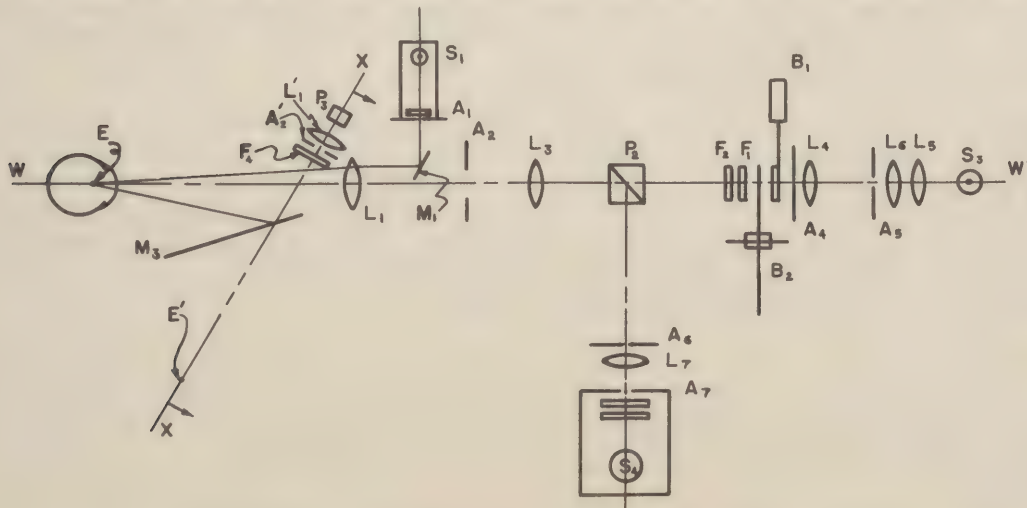


Figure 4. Apparatus.

rest so that the center of the pupil falls at the point E, while the eye fixates the small aperture A_1 or A_7 . Fixation point A_1 is a small aperture backed up by a piece of milk glass and a red filter, and is illuminated by the source S_1 . Through the lens L_1 the eye sees the image of A_1 formed by the mirror M_1 in the plane of the diaphragm A_2 . It is seen displaced 5° to the left of the center of the lens L_1 .

The eye may also fixate the image of the small aperture A_7 formed by the lenses L_7 and L_3 in the plane of the diaphragm A_2 . The small aperture A_7 is backed up by a piece of milk glass and red filter, and is illuminated by the source S_4 . The light passes through the lens L_7 , the small aperture A_6 , the beam splitter P_2 , the lens L_3 , and forms an image of A_7 at the center of the aperture in diaphragm A_2 . Diaphragm A_6 constitutes the aperture stop for this system. An image of this aperture is formed by the lenses L_3 and L_1 in the plane of the entrance pupil which is the same size as the 1 mm aperture.

The apparatus provides two means of exposing bright patches to the eye. One makes use of source S_3 and the other of S'_3 . The light from source S_3 passes through the lenses L_5 and L_6 and L_4 and focuses at the small aperture in the diaphragm A_4 . This small aperture is 1 mm in diameter and constitutes the aperture stop of the system. A 1 mm image of this aperture stop is formed by lens L_3 and lens L_1 in the plane of the entrance pupil.

When the diaphragm A_5 is removed, the entire field of the circular aperture in diaphragm A_2 appears uniformly bright to the eye and subtends a visual angle of 8° . The diaphragm at A_5 can be used to restrict the size of the patch. An image of the aperture A_5 is formed in the plane of the diaphragm A_2 , and this image can be centered in the aperture in the diaphragm A_2 or displaced to the right or to the left of the center by any amount desired.

Several diaphragms are used at A_5 representing apertures of different sizes, and one of these diaphragms contains a pair of apertures one above the other. Each subtends 0.8° visual angle, and they are separated by 1.6° from center to center. These two patches can be exposed alternately by manually moving a shutter blade, located just in front of the diaphragm, which occludes first one and then the other of the two apertures. This shutter blade can also be used to produce intermittent exposure or a prolonged exposure of one of the patches.

When this manual shutter is being used to expose the patches in this particular diaphragm, the rotating sector disk B_2 is lifted out of the path of the beam from S_3 and the electromagnetic shutter B_1 is kept open.

While using the electromagnetic shutter B_1 by itself to control exposures, the rotating disk shutter B_2 is lifted out of the path of the beam. The electromagnetic shutter B_1 when acting alone can be made to provide exposures of 100, 300, 1000 and 3000 milliseconds by throwing the appropriate selector switch. The shutter B_1 and the rotating disk B_2 are synchronized so that the two in combination can be made to provide exposures of 1, 3, 10 and 30 milliseconds. When the two are used together, the onset of the exposure occurs 50 milliseconds after the electromagnetic shutter opens.

The diaphragm at A_2 can be positioned so that the center of the image of its aperture coincides with the image of A_6 , which is the fixation point, or as in one experiment it can be displaced so that the center of the image of the aperture in A_2 will fall 3° to the right of the image of A_6 or again at 6° to the right of the image of the fixation point A_1 .

The neutral filters F_1 and F_2 control the amount of light reaching the eye from S_3 .

For peripheral stimuli at greater angular distances from the principal line of sight

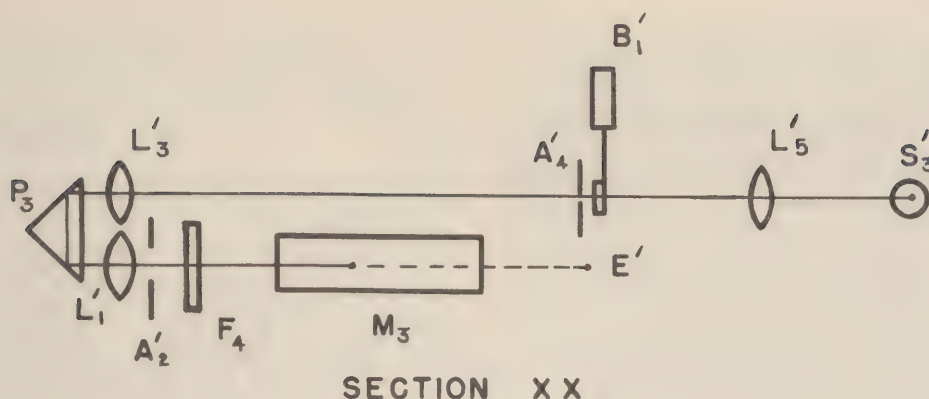


Figure 5. A Vertical Section Showing Part of the Apparatus in Figure 4.

than 6° , a special device was used which involved the fixed mirror M_3 and an optical system swinging about a vertical axis through the point E' , which is the mirror image of the point E . A vertical section of this system along the axis XX is shown in Fig. 5. Light from the source S'_3 is focused by a lens L'_5 at the 1-mm aperture in the diaphragm at A'_4 . This aperture constitutes the aperture stop of the system. An image of this aperture stop is formed by the lenses L'_3 and L'_4 and the mirror M_3 at the center of the entrance pupil of the eye, E . The Porro prism P_3 reflects the light back toward E' . An image of the aperture stop at A'_4 would focus at E' were it not for the fixed mirror M_3 which causes the image of the aperture A'_4 to be formed at the center of the entrance pupil. It has the same size as the aperture A'_4 .

The advantage of this mirror arrangement is that as the optical system swings around E' it gives peripheral stimuli at various angular distances from the point of fixation, and the beam directed toward the eye always passes exactly through the center of the entrance pupil. The aperture A'_2 limits the diameter of this peripheral patch to 1 degree, 7 minutes. A filter F_4 with a transmission of 0.07 was used to give the brightness of the peripheral patch the same value as the maximum value of the patch of brightness provided by S_3 , namely 147,000 trolands. The electromagnetic shutter B'_1 can be controlled by the same timing mechanism as the shutter B_1 .

The system used for recording the changes in pupil size is illustrated in Fig. 6. This system is incorporated as part of the instrument described above. The aperture A_2 , the lens L_1 , and the point E which represents the center of the entrance pupil, are identical with the elements indicated by the same symbols in Fig. 4. The ribbon filament S_5 is mounted in a light-tight lamp house from which the light emerges through the infrared filter F_3 and the lens L_8 . This filter consists of two layers of film produced by the Polaroid Corporation and is designated XR7X25; its properties have been described elsewhere.¹⁰ The light emerging from the lens L_8 is reflected at the mirror M_4 which is below and in front of the eye, and a horizontal image of the ribbon filament is formed in the plane of the entrance pupil of the eye which illuminates the opposite margins of the iris. The lens L_9 , located in front of the eye and below the line of sight, collects the light from the iris and collimates it. This light is reflected by M_5 to the objective L_{10} which focuses an image of the pupil in the plane of the slit in the diaphragm A_7 , with the slit dividing the image of the pupil into upper and lower halves. The image is 1.06 times as large as the entrance pupil of the eye. The slit is parallel to and lies in the plane containing L_{10} , M_5 and E , and the film moves perpendicularly to the direction of this slit. As the film moves behind the slit the horizontal diameter of the pupil registers as a dark band on the film (see Fig. 7), varying in width depending upon the diameter of the pupil. The neon source which has the

form of a small rod is focused by the glass rod as a narrow line on the edge of the film. The neon source is synchronized with the shutters so that one can tell on the film where the onset of the exposure occurred.

In the experiments involving exposures of long duration, intermittent exposure and alternating exposure of two bright patches, one hand was used to manipulate the shutter controlling the bright patch, and the other hand manipulated a switch controlling the neon source. In this way the beginning and end of an exposure or the alternation from one patch to another could be roughly indicated on the film.

The film used was Eastman Infra red Film 104, the characteristics of which have been described elsewhere.¹¹

An electronic circuit was devised whereby the mechanism controlling the electromagnetic shutters B_1 and B'_1 also controls the starting and stopping of the camera motor.

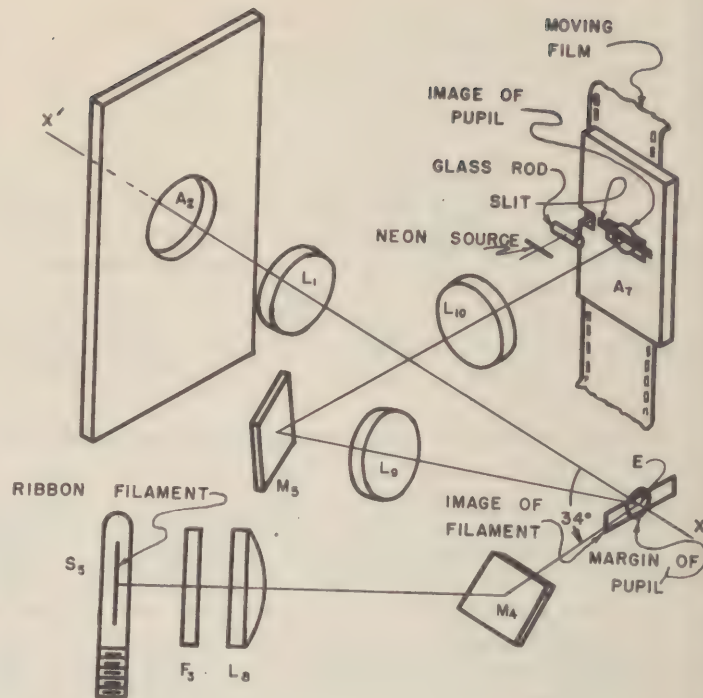


Figure 6. The Part of the Apparatus Used for Recording Pupil Size.

PROCEDURE IN OBTAINING A RECORD

During a recording of pupil size the subject sits with his head in position and his eyes open and fixating the image of A_1 or A_7 .

The first step in making a record is to push a switch which turns on the infrared source. Then a pair of switches are thrown, one turning on the source S_3 or S'_3 and the other turning on the motor which operates the driving and timing mechanism. Then two more switches are thrown at the same time, one of which starts the camera motor while the other operates the electromagnetic shutter B_1 or B'_1 which gives an exposure of a predetermined length. The camera motor starts prior to the exposure and is operating at full speed when the flash comes. The camera motor normally operates for four seconds following the onset of the flash in order to record in full the first four seconds of the response; thereafter the camera operates for a short run at the end of each four seconds, so that at four-second intervals following the flash the size of the pupil is recorded. In this way the decay of the constriction can be traced back to normal over a considerable period of time without using a great deal of film. However, by simply holding a pushbutton switch closed it is possible to prolong the initial continuous run of the motor from 4 seconds to 8 or 12, or 16 seconds, etc.

ANALYSIS OF THE FILM RECORD

The record on the film (Fig. 7) consists of a variable band down the center of the film which indicates the width of the pupil as a function of time. The onset of the flash is indicated by a short line at the edge of the film produced by the time marker. In the case of an exposure of long duration, or intermittent exposure, or alternating exposures of two

patches, time marks are made on the film to indicate both the beginning and the end of the exposures or the alternations from one patch to the other.

For analyzing the data, use was made of a device constructed in this laboratory for analyzing binocular eye movement records to determine the changes in convergence. Essentially what this device does with a film record of changes in pupil size is to transcribe the data to the form of a single curve on a sheet of paper which indicates the changes in pupil size as a function of time. The curves presented in this report are direct traces of the transcribed data. Two different scales for pupil diameter have been used in transcribing the data. The use of two scales serves no useful purpose and was not intended at the outset.

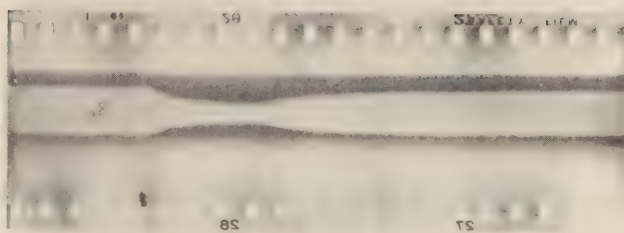


Figure 7. A Reproduction of a Strip of Film Showing a Record of Changes in Pupil Size.

LIMITATIONS OF THE METHODS USED FOR RECORDING CHANGES IN PUPIL SIZE

In order to get a record with enough contrast to be of any use it was necessary to increase the width of the slit to 0.75 mm and to slow down the rate of movement of the film to 11.5 mm per second. Hence, each element of length of the film was given an exposure of 0.065 seconds. The width of the band at any point on the film therefore is an integration of changes occurring within this period of time. In order to measure precisely the beginning of a constriction, the duration of exposure for each element of length of the film should be of the order of a hundredth to a thousandth of a second. Consequently the method as it stands does not represent all that might be desired; it would help to have a more intense source, a more suitable filter or a higher speed film.

Another limitation is the occurrence of blinks just as the pupil constriction gets under way; when such a blink occurs, it interferes with the record. For most purposes, however, records can be used in spite of the occurrence of the blink, particularly if attention is to be concentrated on the minimum size that the pupil attains as a result of the exposure.

SUBJECTS

Two subjects were used in this experiment. One is a graduate student of Physiological Optics and the other is a senior student in the School of Optometry. P.H. is 23 years of age and L.Z. is 39 years of age. L.Z. wore a correcting lens (+.25-.50 x 10) in front of his right eye during the experiment for the correction of his ametropia. P.H. requires a -.50 sph. but wore no prescription. The correction does not interfere either with the presentation of the flash sources or the recording of the pupil size.

ABSENCE OF RESPONSE TO THE INFRARED LIGHT ILLUMINATING THE IRIS

The ribbon filament S_5 , the infrared filter F_3 , the lens L_8 and the mirror M_4 , (see Fig. 6) present to the eye a patch of infrared light (9° in diameter) which is bounded by the edge of lens L_8 . The image of this patch formed by the mirror M_4 is seen in a direction below the center of the aperture A_2 . The visual angle separating the centers of L_8 and L_1 is 34° .

The filter F_3 used to screen out visible light from the infrared transmits light at the extreme end of the visible spectrum so that the subject in this experiment is aware of a faint red patch in the lower part of the field. In order to test whether this red light can

produce a pupil constriction, the film in the camera was set in motion and the source S_5 was turned on for a short period. In neither of the subjects was there any significant change in pupil size following the onset of the infrared source.

RESULTS

A. Pupil Constrictions to Flashes of Various Areas and Brightnesses.

The results considered in this section pertain to patches of brightness 0.8° , 2.64° , and 8° in diameter, centrally fixated, and exposed for 3 seconds. The solid angles subtended are 0.000154, 0.00154 and 0.0154 steradians, respectively.

The series of records for subject P.H. for flashes of various brightnesses shown in Fig. 8B were all made at one sitting, one after the other in the order from low to high brightnesses, with enough time allowed between exposures to permit the return of the pupil to normal and also to permit the retina to return back to its state of dark adaptation. The subject was placed in darkness for a period of 30 minutes prior to the experiment.

The records in Fig. 9I and 9J for P.H. for 3-second exposures of patches of different size and at two different brightness levels were all made at one sitting. The first record made was for the lowest brightness and smallest area. This was followed by records at the same brightness level but for the medium and large areas. The same procedure was repeated at the next brightness level.

The records in Figs. 9A to Figs. 9H for L.Z. were all obtained in one sitting using exactly the same procedure. The records for L.Z. in Fig. 8A are the same as the records for L.Z. for the 8° patch presented in Fig. 9.

Fig. 10, which is based upon the data in Fig. 8A and 8B, shows the relationship between the brightness of the patch and the minimum size that the pupil attains in response to it. The unusually large response for P.H. at 1.47 trolands is not consistent with the rest of the responses. The experimenter could have used the wrong filter, but there was no way of checking up on this possibility. This is the only point at which this sort of deviation occurs.

Fig. 11, which is based on the data for L.Z. in Fig. 9, shows the relationship between the brightness of the flash and the minimum size that the pupil attains in response to it for three different patch sizes.

The data in both Figs. 10 and Fig. 11 suggest that as the area and brightness are increased, an upper limit of pupil constriction is approached. The experiment should be extended to include at least one more log unit at the upper end of the brightness scale, as well as larger areas, in order to permit more definite conclusions to be drawn. If there is a limit to pupil constriction it is probably in the muscle or in the motor centers rather than on the sensory side of the reflex. The maximum response is reached with an 0.8° patch producing a retinal illuminance of 147,000 trolands while, as indicated in Fig. 2, the stray light is only 10 trolands at a point 5° from the edge of the patch and drops to 1 troland at 15° from the edge of the patch. The maximum output of the retina is far from being reached under these conditions.

At the lower levels the responses from the medium and small areas disappear suddenly while the large area continues to produce an effect. This finding tends to support the idea that stray light is the dominant factor in the sense that the retinal illuminance produced by the stray light simply drops below the threshold for the rods in the case of the small and medium targets but is still above the threshold in the case of the large target.

It must be kept in mind, however, that an 0.8° target centrally fixated falls in the fovea, and a 2.64° target is largely confined to the fovea, whereas the image of an 8° patch contains many rods, and one must assume that the rods within this area are responding and contributing to the pupil response when the retinal illuminance in the image of the patch drops below the threshold level of the cones.

At intermediate levels the effect of varying area is equivalent to that of varying intensity. This finding is consistent with the notion that stray light is the important factor. There is nothing in the nature of the curves to indicate at any level a transfer of dominance from elements outside the image of the patch to elements inside, or from rods to cones.

If the high-frequency, low-latent-period response of the photoreceptors inside the image and the low-frequency, high-latent-period response of those outside both contribute to the pupil response, there should be some way of manipulating brightness and area to differentiate between the two effects.

If the size of the area were gradually increased to include the whole visual field, there must be a point at which the ganglion cells inside the image of the patch dominate the situation. The experiments described in this paper involving areas up to 8° should be extended to areas including the whole visual field.

Another method of differentiating between the responses inside and outside the image would be to flood the retina with a uniform distribution of retinal illuminance and then superimpose flashes upon this background. The background could be made to mask the effect of the stray light.

B. Effects of Stimulating Different Areas of the Retina.

The records shown in Fig. 12 are those obtained using 1.12° patches of brightness at various degrees of eccentricity from the fixation point. All of the records in each graph were made at one sitting with the records being made in the order from the largest degree of eccentricity to zero eccentricity. Subjects were kept dark adapted 30 minutes before taking any record. Enough time was allowed between records to permit the retina to return to its original state of dark adaptation and to permit the pupil to return to its normal size under dark adaptation. In the case of L.Z. little or no effect was obtained from changing the eccentricity of the patch of brightness. In the case of P.H. the pupil responses at 32° and 25° of eccentricity are somewhat smaller than the rest, but the rest all approximate the same size.

It is probable that the state of dark adaptation makes the response uniform across the retina. Other investigators have found that the fovea is more effective in producing a pupillary response than the parafovea. This is what one would predict would happen in the bright adapted eye.

It is probably true that the small image focused on the retina is contributing very little to the pupil response. The facts should probably be described by saying that distributions of stray light centered at points at different distances from the fovea produce essentially the same response. Each of these distributions of stray light is itself a gradient and if, for example, the fovea were the only part of the retina producing the pupil response, as was claimed by Hess⁵, then the further the center of the distribution from the fovea the less would be the pupil response.

The fact that, in the dark adapted eye, the periphery of the retina is just as effective in producing a pupil response as the central portion, simplifies the procedure in computing the effects of a complex distribution on the retina because it means that no allowance need

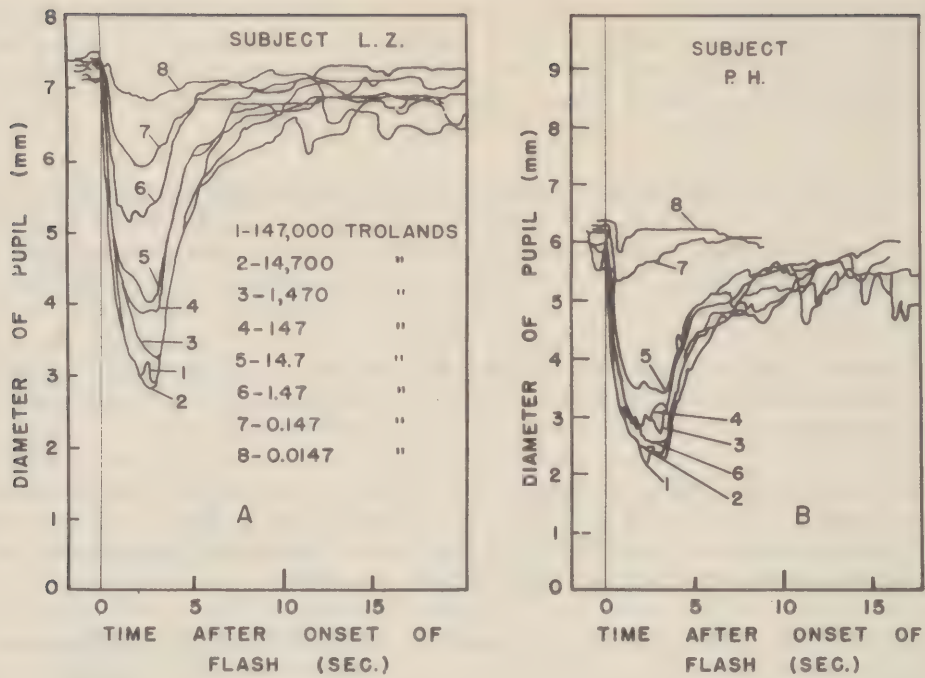


Figure 8. Pupil Responses to 3-sec Exposures of the Right Eye to an 8-degree Circular Patch Centrally Fixated and Producing Various Amounts of Retinal Illumination.

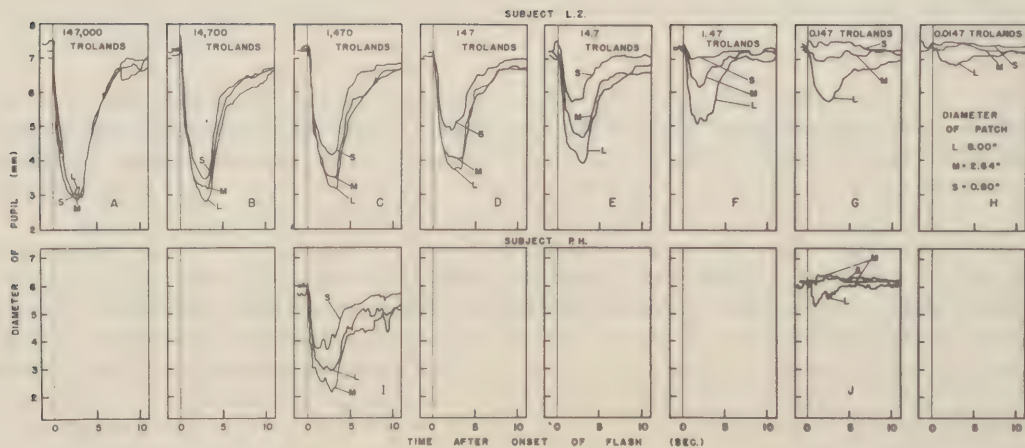


Figure 9. Pupil Responses to 3-sec Exposures of the Right Eye to Circular Patches of Brightness Centrally Fixated and having Various Sizes and Producing Various Amounts of Retinal Illumination.

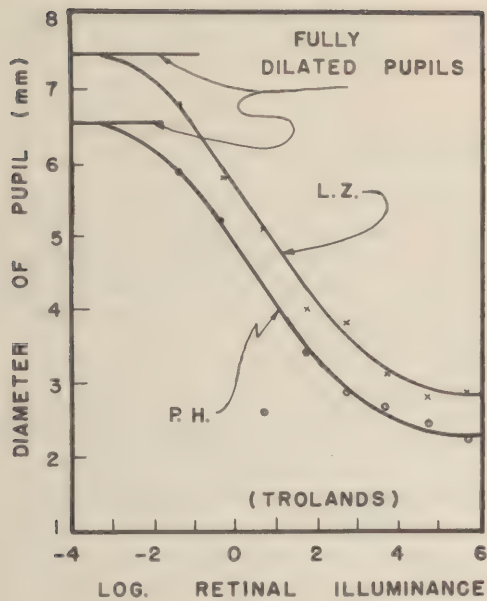


Figure 10. Analysis of the Data in Figure 8 showing the Minimum Pupil Diameters Attained in Response to the Flashes.

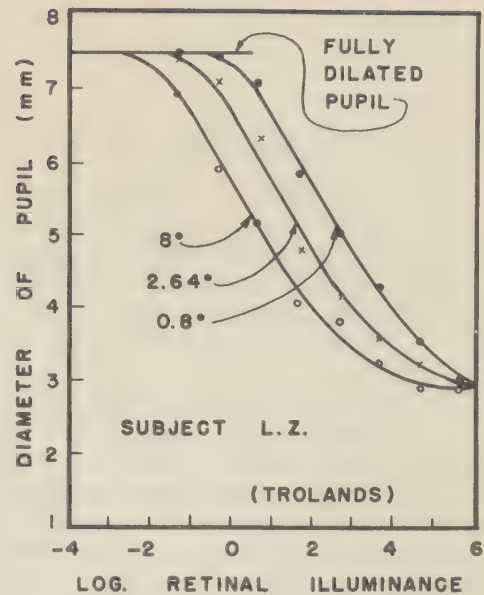


Figure 11. Analysis of the Data in Figure 9 showing the Minimum Pupil Diameters Attained in Response to the Flashes.

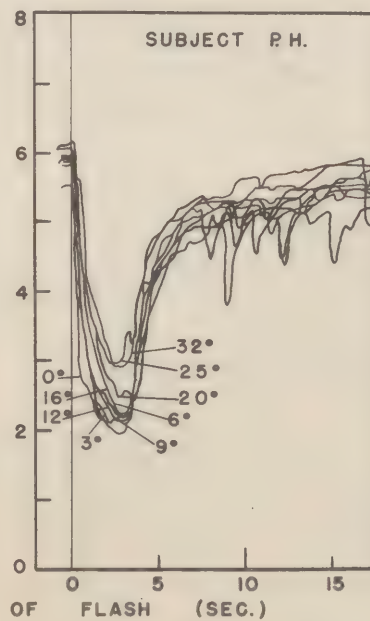
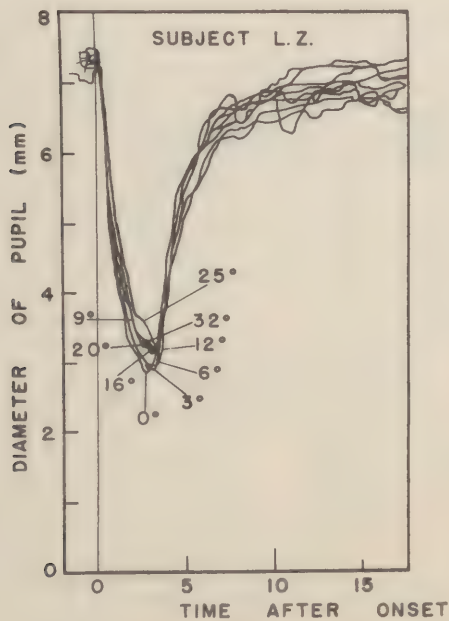


Figure 12. Pupil Responses to 3-sec Exposures of the Right Eye to a 1.128 Bright Circular Patch (147,000 trolands) Placed at Various Distances From the Fixation Point.

be made for the location of a patch on the central region of the retina. All patches, regardless of where they fall within the central region of the retina, would be equally effective.

C. The Role Played by Stray Light in Producing Pupil Responses.

When the patch 1.12° in diameter falls 16° to the right of the fixation point, it falls within the blind spot of each subject as shown in Fig. 13. The pupil response, however, is just as great as the response obtained from areas to the left and right of the blind spot (see Fig. 12). This is in accordance with the finding of Hess⁵ and it can probably be concluded from this that the stray light produced by a small bright patch is the important thing rather than the light which is focused directly on the retina.

One method employed in this study for demonstrating the role played by stray light is similar to that used by Bartley and Fry¹² in demonstrating the role played by stray light in producing the retinal potential. The technique consisted in alternating two patches of light 0.8° in diameter, separated from each other by 1.6° (center to center) and each separated 5° from the point of fixation, and with the midpoint between the two patches being on a horizontal line through the point of fixation. As explained in the procedure, the alternation is accomplished manually by throwing a shutter which exposes one stimulus and then the other. This shutter can also be used to occlude both stimuli.

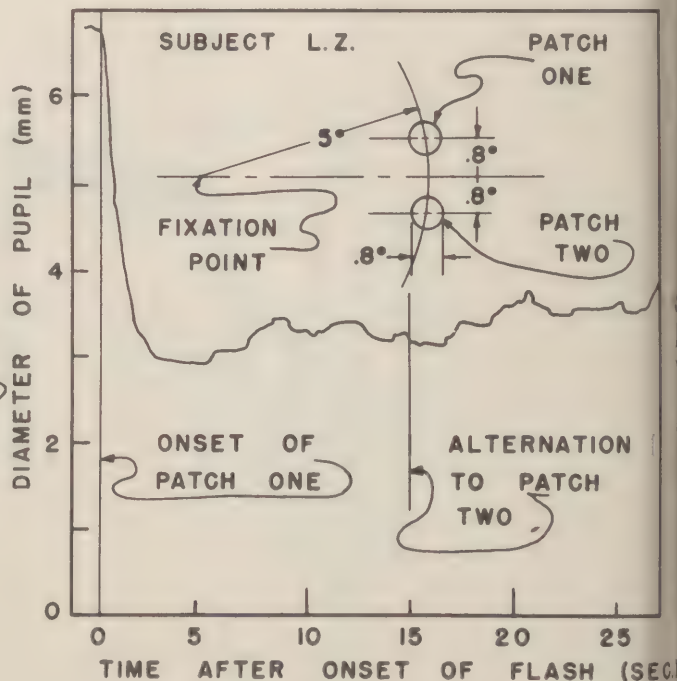
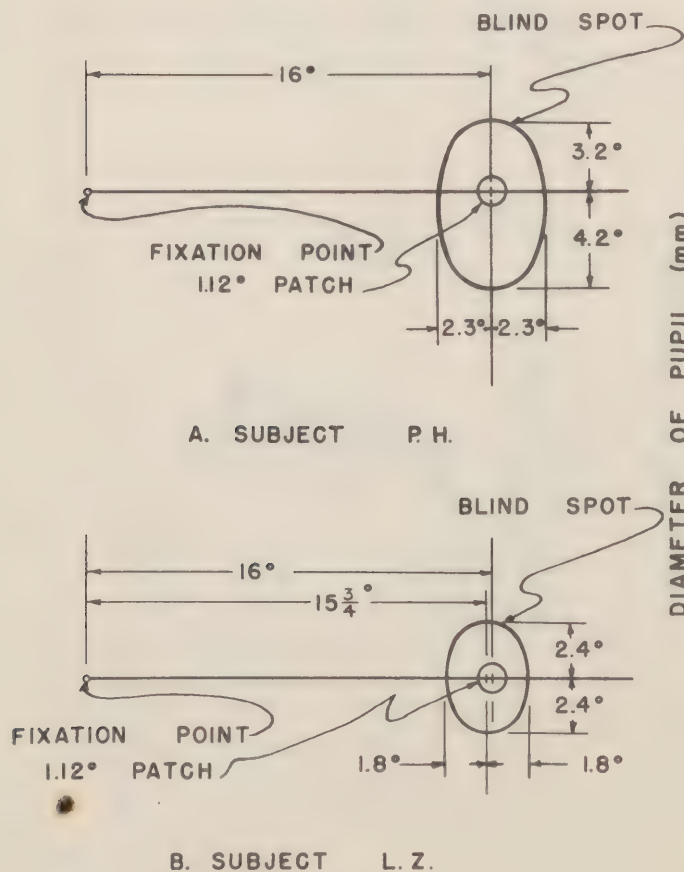


Figure 13. Location of the 1.12° Patch Within the Blind Spot of Each Subject When Placed 16° to the Right of the Fixation Point.

Figure 14. The Effect of Suddenly Switching from One Patch to Another. Each Patch Produces a Retinal Illumination of 147,000 trolands.

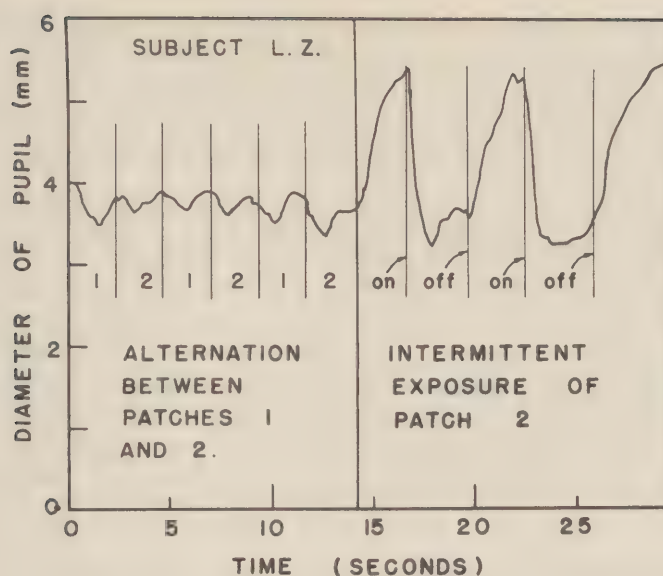


Figure 15. The Effect of Alternation From One Patch to Another. The Patches Are the Same as the Ones Referred to in Figure 14. The Beginning of this Record Occurs at the Middle of a Series of Alternations, and at the Middle of the Record the Stimulus Pattern Was Switched from an Alternation of Two Patches to an Intermittent Exposure of One Patch.

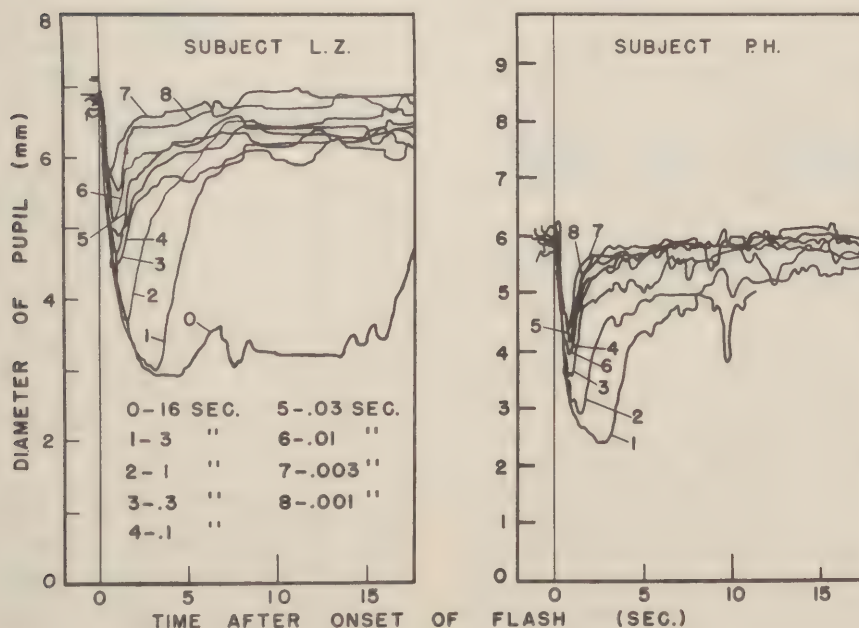


Figure 16. Pupil Responses to Exposures of the Right Eye to an 8° Bright Circular Patch (1,470 trolands) Centrally Fixated for Various Durations.

If the pupil response produced by these patches were mediated by the stray light in the eye one would not expect any fluctuation in pupil size to occur at the switch from one patch to the other, because the difference in amount of stray light produced by the two patches at a given point of the retina could not be very great, except in the case of a point which is very close to one or the other of the images of the two patches.

The pupil response shown in Fig. 14 was obtained by keeping the subject in the dark for 30 minutes, and after this exposing one of the patches for 16 sec, then suddenly switching to the other patch.

The first part of the record in Fig. 15 shows the response of the pupil to rhythmic alternation back and forth from one patch to the other. The fact that the fluctuations in pupil size are more pronounced and more regular with alternating patches than with the steady stimulation of a single patch (Fig. 14) indicates that the intermittent activity of the photoreceptors in and near the images of the patches does introduce a rhythm into the pupil constriction. The second part of the record in Fig. 15 shows the response of the pupil to an intermittent stimulus.

D. Effects of Varying Duration of the Flash upon the Response of the Pupil.

Records obtained with flashes of different duration are shown in Fig. 16. In each case the diameter of the circular patch was 8° , the retinal illuminance produced by the patch was kept constant at 1470 trolands, and the fixation point was at the center. Prior to obtaining any record each of the subjects was kept in the dark for 30 minutes, and then the records were taken in the order from long to short in the case of P.H. and from short to long in the case of L.Z. with enough time allowed between records to permit recovery to the dark adapted state and to permit the return of the pupil to its normal size. The data in Fig. 16 have been analyzed in Fig. 17 to show the minimum size that the pupil attains with flashes of different durations.

By comparing Figs. 8, 9, 10, 16, and 17 it is easy to observe that the effect of varying brightness is not at all equivalent to varying duration. The recovery from short flashes of high brightness is much faster than from weak flashes of long duration. The extent of pupil constriction finally reaches a limit as the duration of the stimulus is increased to one of indefinite duration, and this limit bears no relation to the limit reached by varying brightness and area.

The photoreceptor response to a flash of light is a burst of impulses which builds up to a maximum frequency and then subsides. For short flashes, the height of this peak is assumed to be affected just as much by varying intensity as by varying duration, but there is a critical duration (ranging from about 0.03 sec for cones at high brightness levels to 0.20 sec for rods

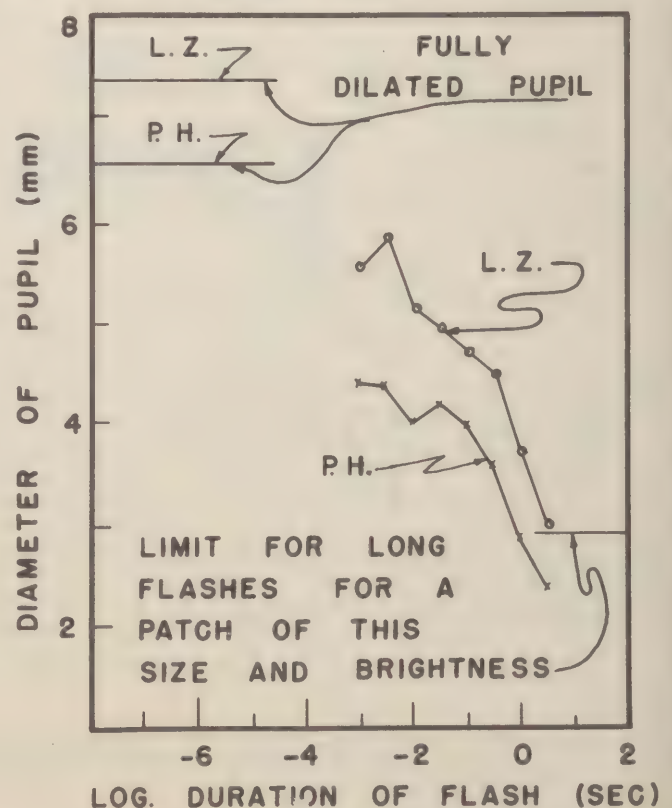


Figure 17. Analysis of the Data in Fig. 16 Showing the Minimum Diameters Attained in Response to the Flashes.

at low brightness levels) beyond which further increase in duration will not increase the size of the peak. Further prolongation of the stimulus keeps the wave of activity from subsiding to zero; a low level of activity is maintained as long as the stimulus lasts. In contrast to this pattern of activity of the photoreceptors, the pupil continues with its wave of constriction long after the wave of activity of the photoreceptor has passed its peak and subsided to a reasonably steady level. It does not reach its peak until after about three seconds. After passing by the peak of constriction the pupil dilates a little, and after this it maintains a fairly constant level. The pattern of impulses transmitted by the photoreceptors to the ganglion cell layer and the pretectal region is probably retransmitted with high fidelity to the Edinger-Westphal nuclei, the ciliary ganglions and the sphincter muscles of the irides. It would appear, therefore, that the volley of impulses associated with the onset of the flash is expended in getting the sphincter response under way, but the sphincter response continues to build up after the volley of impulses has subsided to a lower level and continues to build up until it reaches its maximum several seconds later. The slight dilation of the pupil to its final steady size, which follows this peak of activity, probably depends upon a gradual decay of activity at the photoreceptor level. When the pupil finally reaches its steady state, it takes a relatively low frequency of impulses from the retina to maintain the pupil in its constricted state.

On the other hand, if we keep the duration of the flash constant and vary the brightness, we might expect the peak of the volley of impulses initiated in the retina to shift forward in time and the frequency of impulses at the peak to increase; and also if the duration is long enough for the frequency of impulses to settle down to a reasonably steady level before the flash ends, the level of retinal activity following the peak will be affected.

E. Recovery from a Flash.

In Fig. 18 the recovery from 3 sec, 8° , centrally fixated flashes at various brightness levels have been traced for several minutes following the flash. A continuous record has been made of pupil size during the first 8 sec (low brightness) or 12 sec (medium brightness) or 28 sec (high brightness), and thereafter at the end of every four-second interval a short record of pupil size was made.

Our records indicate that if the pupil of an eye kept in darkness is made to constrict by a flash of light, it will return back to its original size within the first minute following the cessation of the flash.

It is not known whether the course of this recovery is determined wholly by the mechanics of the muscle or whether prolonged activity of the sensory mechanism is a factor. For example, there must be some kind of after discharge in the sensory mechanism associated with positive after images.

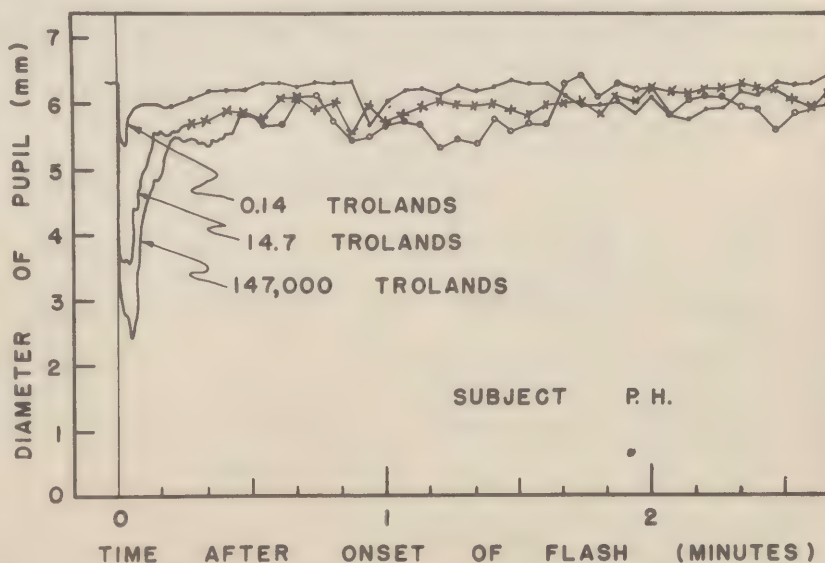


Figure 18. The Recovery of the Pupil from Responses to 3-sec Exposures of the Right Eye to an 8° Centrally Fixated Patch at Various Brightness Levels.

SUMMARY AND CONCLUSIONS

Insofar as a flash of light in the visual field which one might encounter in a practical situation is similar to any of the stimuli which have been employed in this situation, the results of this investigation can be used directly to predict the effect of the flash upon pupil size during the flash and upon the ability to see immediately following the flash.

There are two aspects to the problem. If the flash lasts longer than the latent period for pupil constriction, the pupil constriction will affect the amount of light reaching the retina during the later portion of the flash. The second aspect of the problem relates to what happens subsequent to the flash. The pupil does not return back to its normal size until after a considerable period of time, and consequently this constricted state of the pupil must be taken into account in evaluating the return of an observer's ability to see a dark object against the sky background.

It was hoped that this study would lead to an adequate method of predicting the course of the pupil response produced by a flash having a complex temporal pattern as well as a complex, changing distribution of brightness in the visual field. In attempting to do this the obvious procedure is to determine the changes in the total retinal illuminance at various points on the retina during the period of the flash. This includes stray light as well as the light directly focused on the retina. Having done this one must predict the frequency of impulses discharged by the ganglion cells at the different parts of the retina at the different times, and then he must figure out how the impulses from the different parts of the retina summate with respect to both space and time to determine the pupil response.

As pointed out previously there are many problems which need further study before one can hope to predict the course of the change in pupil size resulting from a complex temporal pattern and also a complex, changing distribution of brightness in the field of view.

Until the mechanisms of temporal and spatial summation are better understood, it will probably suffice to use some crude approximations for predicting pupil responses. In the case of the dark adapted eye one can assume that the response is proportional to the total amount of light involved (brightness $\times$ area $\times$ time). This will hold roughly for the central region of the field of view up to 35° out from the primary line of sight and for flashes up to 0.2 sec. For longer flashes than 0.2 sec the effect of varying duration is not the same as that of varying brightness, and allowance must be made also for the effect of the pupil constriction itself.

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THE EFFECT OF LOW LEVELS OF LUMINANCE AND FREEDOM FROM OPTICAL STIMULATION OF ACCOMMODATION UPON THE REFRACTIVE STATE OF THE EYE

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INTRODUCTION

It has been pointed out in an earlier paper¹ by this author that the so-called "nocturnal or night myopia" and the increased refractive state of the eye associated with the absence of optical stimulation of accommodation are in many respects similar. The "myopia" associated with reduced levels of luminance has been investigated by Tousey, Otero, Ivanoff, and others.¹ The latter phenomenon has been reported by Luckiesh and Moss,² Reese,³ and Reese and Fry.⁴ It is the purpose of this study to extend the measurements of this second group of investigators to determine the changes of the refractive state of the eye with and without stimulation of accommodation for several levels of luminance.

APPARATUS

In Figure 1(A) is shown the arrangement of the apparatus which was designed and used to verify the findings of Luckiesh and Moss and Reese and Fry and to extend them over the luminance range from approximately 25 C/M^2 to 0.001 C/M^2 . The apparatus can be conveniently divided into two parts, the observing and accommodating measuring unit shown at the left in Figure 1(A) and in detail in 1(B) and the target projecting unit at the right in Figure 1(A). The former consisted of two beam splitting cubes B and B', through which the observer could view the target which was seen at GG₁ at 4.4 meters distance and also with his left eye see the image of the slit T, as formed by the lens A, super-imposed on the target. The entrance pupil of the subject's left eye was placed at the posterior focal point of lens A, thus forming a telecentric system in which the slit would subtend the same angle at the entrance pupil for all positions of the slit along the axis of the system. The slit T was illuminated by the system S, O₁, and O₂. S was a 7 1/2 watt frosted lamp which illuminated opal glass O₁, which in turn illuminated opal glass O₂. I was an iris diaphragm which allowed the luminance of the surface of O₂ to be varied continuously over about a twenty-fold range. For larger variations of luminance, Wratten neutral density filters were placed at F. By these two means the luminance of the slit

Table I

Angular dimensions of circular target shown in Figure 1(C)

Ring No.	Inside Radius	Width
1	11.7'	1.6'
2	16.4'	2.4'
3	30.5'	28.9'

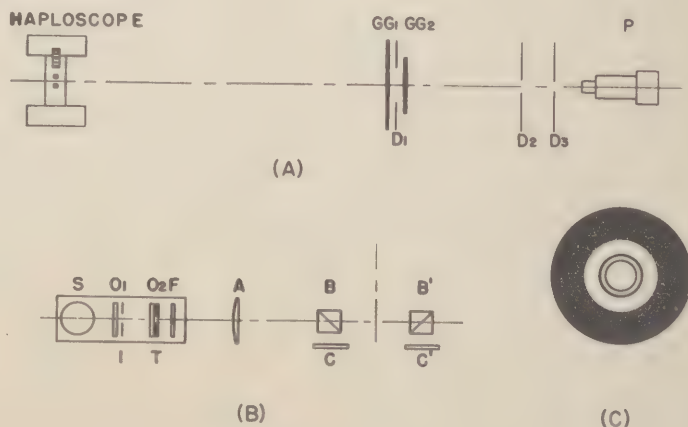


Figure 1.

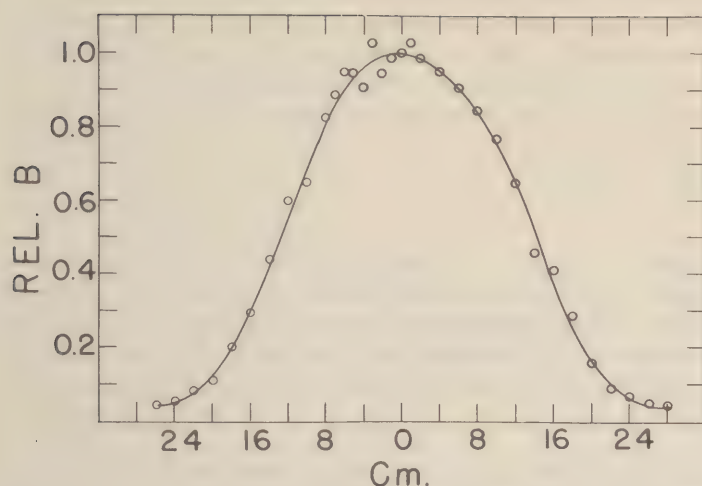


Figure 2.

would be devoid of any contrast borders and thus not stimulate accommodation and yet subtend a large enough angle to provide an adequate target for convergence and fixation and also maintain the eye at a constant level of adaptation during slight variations in fixation. The intensity distribution aimed at was that of a normal frequency distribution curve, and the relative luminance values as measured by means of a Macbeth Illuminometer shown in Figure 2 indicate the success of the design. The subjective appearance is that of a "blob" of light, which defies all efforts to clear the image - a somewhat frustrating experience to the observers at the outset of their training. The angle subtended at the subject's eye by the two limiting values shown was 7.2 degrees.

This distribution of luminance on GG_1 was obtained in the following manner. A standard projector P, was used to project an out of focus image of a circular hole in a black piece of cardboard on the right hand surface of GG_2 . GG_2 was a piece of 1/4 inch plate glass sand blasted on both surfaces. The diffused light passing through this sheet of glass then illuminated GG_1 which was a similar piece of plate glass sand blasted only on the surface facing GG_2 , the surface facing the observer being plane and polished. The resulting "blob" is described quantitatively by the luminance distribution shown in Figure 2. Diaphragms D_1 , D_2 , and D_3 were placed to eliminate stray light from striking the glass plates. The entire apparatus was located in a darkened room with flat black walls, so that the observer saw before him the blob in a totally dark field.

The over-all intensity of the blob was varied by any of the following means. (1) Placing a piece of ground glass between the condensing lenses of the projector, (2) reducing the intensity of the projection bulb by placing an aperture covered with a piece of ground glass between the bulb and the condensing lenses, and (3) placing neutral density filters in the projected beam.

The target shown in Figure 1(C) was used as an accommodation stimulating target. That it was an adequate stimulus to accommodation at high levels of luminance will be shown in the section on results. It was also used to determine at what levels of luminance this sort of target no longer acts as an adequate stimulus to accommodation. It consisted of three concentric black circles, whose angular dimensions are given in Table I, drawn with india ink upon a piece of plastic which could be placed over the polished surface of GG_1 . Since the black circles were completely opaque they provided a maximum contrast target at all levels of luminance.

could varied continuously over the entire required range. All the elements between and including S and F were mounted in a brass tube which could be moved along a horizontal axis perpendicular to the observer's line of sight. This system in conjunction with the beam splitting cube B and the lens A constituted the accommodation measuring device. The manner in which it was used will be described in the next section. Lens cells C and C' were designed to hold lenses from a precision trial lens set which were used to vary the stimulus to accommodation.

The target projecting system shown at the right in Figure 1(A) was designed to produce a target which

Four luminance levels were used in making the measurements in the range from approximately 25 C/M^2 to 0.0010 C/M^2 . This range was for the center of the blob, and was therefore the maximum luminance for a given level. The transmission of the plastic sheet on which the concentric circles were drawn was experimentally determined to be 0.93, therefore this slight correction should be applied to the luminance values of the blob when using the accommodation target.

PROCEDURE

The procedure in general was to measure the state of refraction while the subject was attempting to maintain the blob and the target as clear as possible for the various luminance levels and for various accommodative stimuli. The luminance levels used were 26.5, 1.51, 0.102, 0.0102, and 0.00102 C/M^2 . The targets were viewed at a distance of 4.4 meters, which corresponds to 0.23 diopters. In addition to this, plus and minus lenses were added to give the various accommodative stimuli.

In order to be able to measure the state of refraction without further stimulating accommodation, the following technique was used. The luminance of the slit (T, as described in the last section), while in best focus, was adjusted so that it was approximately one JND above the level of the blob. Now if the slit was thrown out of focus, the intensity distribution on the retina would be such that the slit would be invisible. Two limits were defined by moving the slit from invisibility to points where it first became visible. These could be assumed to lie at equal distances from the true point of least subjective blur. In this manner, three readings were taken on either side of the point of least subjective blur and the average of these six readings taken to be the state of refraction of the eye.

The measurements were made monocularly and binocularly and were always carried out in decreasing order of luminances. The preliminary adjustments were carried out at the highest level, and the time required to adjust the luminance of the targets and slit was sufficient for dark adaptation. The procedure of making the adjustments will be described for the monocular readings in which an occluder was placed in the right lens cell and it need only be mentioned that an adjustment for the interpupillary distance was the only further change in adjusting for the binocular readings.

The subject's head was fixed in position by means of chin and forehead rests, the head being moved to a position where there was a minimum of apparent lateral movement of the slit as the slit assembly was moved back and forth along its axis. The arm of the haploscope was next rotated to the position where the observer reported that the slit was centered in the blob. With the slit thus centered and in best focus, the experimenter next closed the iris diaphragm until the subject reported that he could no longer see the slit. If the slit was still visible when the diaphragm was at its smallest setting, a neutral density filter was inserted to render the slit below the threshold. Now while slowly opening the diaphragm, the subject was asked to report the level at which the slit was visible approximately 75 per cent of the time. After this setting had been made, several trial settings were made to check the spread of the readings and to acquaint or reacquaint the subject with the method of making the settings. The slit assembly was moved along the arm of the haploscope by means of a rack and pinion. The pinion had mounted on it a large circular disc which the subject manipulated with his left hand. Six settings were made for each of the accommodative stimuli, making all the settings for the blob first and then the settings for the accommodative target. When a given luminance level had been completed, the level was reduced and the above procedure repeated.

The procedure of making six settings for each accommodative stimulus proved to be very tedious and tiring for the subject. Therefore the following method was tried and adopted as the procedure used to obtain part of the data. The above procedure applies to all but the setting of the slit in this later method. After the luminance of the slit had been adjusted,

the subject was requested to fixate the center of the blob or the center of the concentric circles target. With the subject thus readied, the experimenter covered the slit with a black occluder and set the slit assembly to the expected point along the haploscope arm. With the slit in this position, the occluder was removed for a fraction of a second and then returned. The subject was requested to tell whether or not he had seen the slit. If the report was in the negative, the slit assembly was reset and the slit exposed again. In this manner, the slit assembly was readjusted until the subject reported that the slit was seen in its clearest position. This point of best visibility was bracketed to make sure that the position was the optimum setting.

This method has several advantages. It is faster than the above method and thus tends to tire the subject less. It eliminates the motor participation of the subject in the making of the settings and thus prevents any bias from entering into the procedure. Finally, the measurement is obtained without further calculation and thus saves time for the experimenter.

In order to verify the results found by the above method, and in an attempt to factor out the effects of pupil dilatation and spherical and chromatic aberrations, the following procedure was followed on the haploscope. The haploscope has been described elsewhere⁵ and therefore has not been included in the section on apparatus.

The method used on the haploscope to measure accommodation consisted of projecting the light from two slits into the eye through two narrow vertical areas in the pupil after passing through a single slit aperture. The areas in the pupil were each 0.3 millimeters wide and were separated by 2.0 millimeters. The subject saw the two slits, one above the other and if the retina was conjugate to the slit aperture, the slits were seen aligned. The system is essentially a modified Scheiner Disc system, with the advantage of a vernier setting, which made very accurate readings possible.

Since the light entered the eye through fixed areas of the pupil, spherical aberration did not effect the measurements of accommodation. The light source used to illuminate the slits was a sodium vapor lamp. Thus the possible effects of chromatic aberration were eliminated.

The measurements were made in the same manner as that described using the blurred slit technique and the flash method, except that it was not possible to reproduce the blob to be used as a haploscope target. The measurements were made binocularly and monocularly at various luminances and accommodative stimuli using concentric circle targets similar to the one used in the above apparatus. The arms of the haploscope were always kept parallel. The measurements were made at the following luminance levels, 30.6, 0.306, 0.00306, and 0.000306 C/M², and at the following accommodative levels, -1.00, 0.00, 1.00, 2.00, 3.00, and 4.00 diopters.

The people who served as observers were chosen from the Juniors and Seniors of the School of Optometry and Graduate students in Physiological Optics.

RESULTS

In order to determine the adequacy of accommodative stimulation by the target and blob, the states of refraction of the eyes of four subjects were measured at accommodative stimuli from -0.77 to +3.23 diopters. The measurements were made monocularly at a luminance level of 26.5 C/M². The tests were carried out monocularly to avoid the possible reduction in accommodative response to maintain fusion. The highest luminance level was chosen since at lower levels it was found that even the target was no longer an adequate stimulus to accommodation.

The average values are plotted in Figure 3. It will be noted that although the blob did elicit a partial response at the higher levels of accommodative stimulation the response was relatively constant from -0.77 to $+2.00$ diopters. It is also significant that the response to the blob was greater than that to the target below the $+0.25$ diopter stimulus level.

That the blob does not appreciably stimulate accommodation was later borne out by other measurements the results of which are shown in Figures 6 and 7 and which will be discussed later. It will be shown there that the refractive state was not changed when minus lenses were used at the highest level of luminance used, but also at all the luminance levels investigated.

Just why a blob should stimulate accommodation at all is not clear. A possible explanation is that the reduction in apparent size of the blob in some manner stimulated the accommodative mechanism. Another possible explanation is that the minus lenses did increase the apparent blur, which could be reduced, but, of course, not eliminated by accommodation. This was borne out by the simple experiment of quickly placing a minus three diopter lens before the eye while observing the blob. It was noticed that the apparent blur did increase and that the blur could be reduced by accommodating.

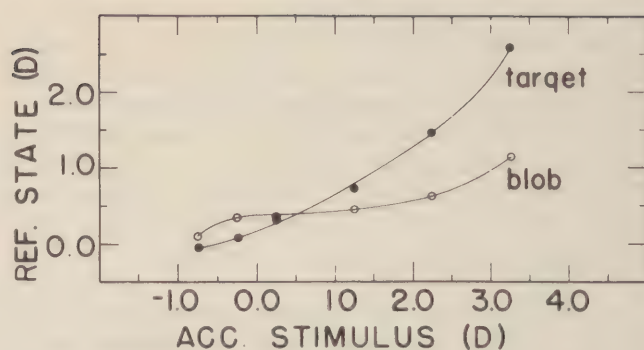


Figure 3.

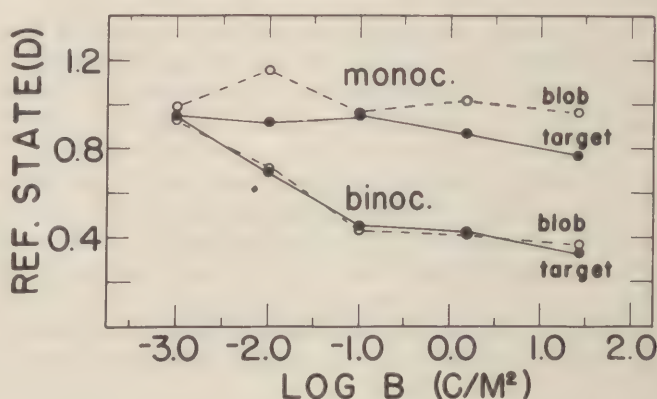


Figure 4.

In Figure 4 are shown the results of two experiments designed to determine the refractive state of the left eye while observing the blob and the target monocularly and binocularly at various luminance levels. The target and blob were observed at 4.4 meters and thus served as accommodative stimuli of $+0.23$ diopters. Those subjects who were not emmetropic wore their distance corrections. The binocular experiments were carried out with five subjects, the monocular with four subjects - in no case did any one subject serve in both experiments. Because of this, the two sets of data cannot strictly be evaluated with respect to each other.

For binocular vision there was no significant difference between the state of refraction while observing the blob and the target. At the highest level, the subject's refractive state corresponds roughly to the stimulus and increased slowly as the luminance level was decreased to about 0.1 C/M^2 , and then increased more rapidly as the level was further reduced to 0.001 C/M^2 .

In the monocular situation there was a difference between the blob and the target, the refractive state being greater for the blob than for the target. The refractive state did increase as the luminance level was reduced in the case of the target, but not for the blob. It may be noticed that the increase was slight and the curve does not show the change in slope shown in the binocular situation. The fluctuations in refractive state shown for the blob are probably not significant, and on the whole the state of refraction remains constant at a level about that for the target.

The fact that the blob and the target were so similar in the binocular situation may be explained by the effect of convergence. The convergence could act as a stabilizing factor maintaining accommodation at a level commensurate with the position of the lines of sight for a point of fixation at 4.4 meters. Apparently, it did not matter whether the fixation target stimulated accommodation or not.

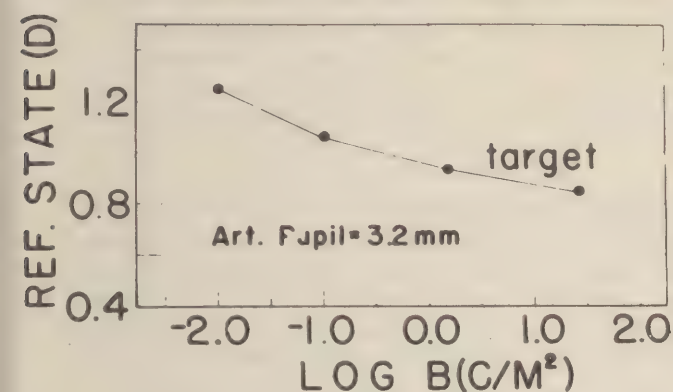


Figure 5.

As the luminance level was reduced, the state of refraction increased. This might have been due to an actual increase in ciliary action. If this increase in the state of refraction were due to ciliary action it would mean that a certain amount of negative fusional convergence would have to be brought into play to maintain single vision. This might not, of course, be necessary if it were assumed that the fusional areas enlarge at lower luminances and that the magnitude of fixation disparity increased.

That the effect must be primarily accommodation can be deduced by comparing the binocular and monocular curves at the highest level. Although they cannot be strictly compared as pointed out above, it was reasonable to assume that the state of refraction monocularly was greater than that binocularly since all the subjects were either emmetropic or corrected for distance. This would mean the initial difference between the monocular and binocular situations was due to greater ciliary action in the monocular situation. Whether the slight increase (0.18 diopters) in the monocular situation was due to further ciliary action is problematical.

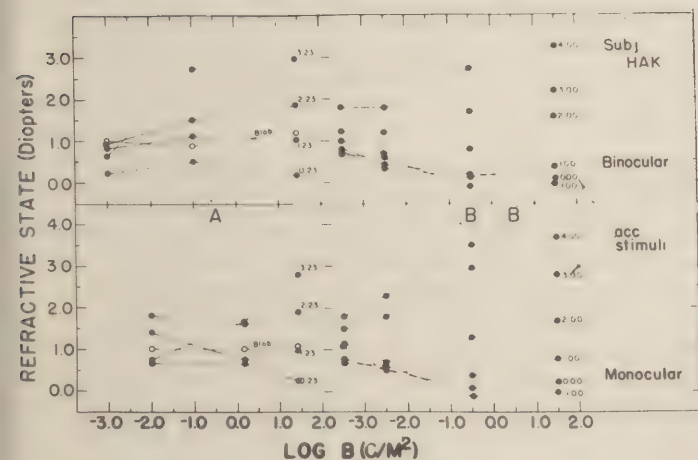


Figure 6.

In an attempt to resolve this problem and in an attempt to discover the cause of the rise in the state of refraction in the binocular situation, the state of refraction of five subjects was determined using an artificial pupil 3.2 millimeters in diameter while keeping the target as clear as possible. Controlling the pupil in this manner ruled out the possible effects of spherical aberration and the results should have indicated only changes in ciliary action.

The average values are plotted in Figure 5. The total average increase in

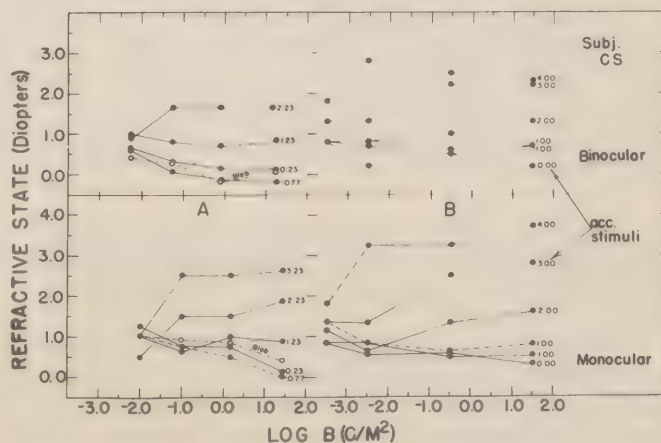


Figure 7.

the state of refraction was 0.39 diopters. Of the five subjects used, three showed an increase, one showed a decrease, and one showed essentially no change. These results indicate that at least a part of the increase in the monocular situation with the target was due to ciliary action.

Further evidence that ciliary action causes the increase in the refractive state was shown by the results of the monocular blob curve in Figure 4. Here the accommodation was initially the highest of the monocular and binocular curves and did not appreciably increase as the luminance was reduced. The ciliary response was apparently maximal at the outset and did not change even though the pupil must have dilated as the luminance level was reduced.

Figures 6 and 7 show the results of a complete investigation of two subjects using most of the luminance levels, all of the accommodative stimuli, and using both the blurred slit and the vernier slit methods of measuring the state of refraction. The measurements were made monocularly and binocularly, using the blob and the concentric ring target with the blurred slit technique and the concentric ring targets on the haploscope. The results using the blurred slit technique are plotted on the left side of the figures, and the results using the vernier slits are plotted on the right side. The figures shown to the right of the curves indicate the accommodative stimuli used in each case to obtain the data.

The blob data for both subjects indicated that the blob was not an adequate stimulus to accommodation for any of the accommodative stimuli at any of the luminances used. For this reason, all the data for the blob at a given luminance level were averaged and this value plotted and the points connected by a dotted line. The responses to the blob do not follow the pattern shown in Figure 4, although the responses shown here do not conflict with those shown in the earlier experiments.

In the case of subject HAK the state of refraction was constant at all luminance levels observing monocularly and binocularly. This agrees with the monocular data shown in Figure 4. That the binocular data are almost identical may mean that the effect of convergence was not sufficient to restrain the accommodation, that the negative fusional convergence range was large enough to allow the lines of sight to remain parallel and allow the subject to exert as much accommodation in the binocular as in the monocular situation. The zone of single clear vision of this subject was known to be of the type that would permit this type of response. The response shown by CS was more like that shown by the group of subjects. Why these differences exist in the binocular situation is not clear at the present.

It may be noted that the state of refraction increases as the luminance level is reduced when the lower accommodative stimuli are used, and that the state of refraction decreases in the case of the higher stimuli. The dotted portions of the 4.00 curves in the case of CS is indicated in this manner since the state of refraction for the lowest luminance could not be accurately measured. The point shown is the limiting position of the carriage on the haploscope. Actually, then, this point would be somewhat lower.

These results indicate that a target which was an adequate stimulus to accommodation at the higher levels of luminance becomes less and less so as the luminance level is reduced. This is related to the effect which has come to be known as "nocturnal presbyopia."¹

When these accommodative stimuli were presented at the lower levels, the subjects were requested to accommodate voluntarily and to report the effect of this accommodation upon the appearance of the target. That the subjects did actually accommodate could be shown by the position of the accommodative measuring carriage when the slits, as seen by the subject were aligned.

The interesting result of these experiments was that the voluntary accommodation did

not improve the appearance of the targets and hence, there was no reason for the subject to exert accommodation. The primary purpose of accommodation is to maintain the stimulus as clear as possible, with the further function of acting in association with convergence to maintain single vision. Since further accommodation does not improve the appearance of the target, the primary function is accomplished in the most economic manner. It may be argued that accommodation may be inhibited since in order to maintain single vision the lines of sight must stay compatible with the secondary function. However, it may be noted that the same effect is present in the monocular situation.

There appears in Figure 7 what seems to be a contradiction of the generalization that the refractive state decreased as the luminance level was decreased. It is the 4.00 curve in the binocular group. This subject has a low negative fusional convergence range. For this reason, the accommodative response at the high levels will be restricted when the lines of sight are maintained parallel. As the luminance level was reduced, the restraint to accommodation due to the requirements of maintaining single vision was reduced because the definition of the target rapidly falls off as the luminance level was reduced. The characteristic drop in refractive state came after the next to the lowest level, when the act of accommodation no longer improved the definition of the target.

Observations of the changes of the IIIrd Purkinje-Sanson Image, pupil size, and convergence with Infra-red equipment,⁶ provide conclusive evidence that the lens, pupil, and convergence changes associated with accommodation are present in complete darkness just as they are at higher levels. Just why the accommodation does not vary at these low levels, in an attempt to clear the image, is not clear.

The increase in refractive state shown in response to the lower accommodative stimuli with decreased luminances deserves special attention since the experiments were designed with the hope of being able to determine whether or not these increases were due to accommodation or to the combined effects of spherical aberration and the dilatation of the pupil. The effect of chromatic aberration was probably absent in these experiments since the lowest luminances used were just about at cone threshold, and thus the effect of the shift in spectral sensitivity was not realized.

It will be noted that the refractive state increased with a reduction in luminance in the case of the vernier slit technique as well as in the blurred slit technique, especially in the case of CS. This has been taken to indicate that the increase in refractive state shown is the result of ciliary action. This does not mean that spherical aberration is ruled out. Later data have shown that there must be some effect due to spherical aberration, which for some reason, not clear at this time, did not enter the determinations made with the blurred slit technique. It must be kept in mind that up until now, none of the measurements correspond to the determinations made by other workers in the field. The measurements reported thus far relate only to the state of refraction for given accommodative stimuli at various levels of luminance. Thus far, no determinations have been made of the optimum stimulus distance, or the optimum spectacle correction for vision at these levels. These measurements were made in the next group of experiments.

Five subjects were used in this series of experiments in order to compare a larger group of measurements made with the blurred slit technique and the vernier slit technique. Each subject's refractive state was measured while observing the blob in the instrument described in the section on apparatus and the targets in the two instruments. The blob and the target were observed at 4.4 meters in the one method and with the targets set at a stimulus distance of +0.23 diopters on the haploscope arms.

When the lowest luminance level was reached on the haploscope, the following readings were taken in addition to the state of refraction to the 0.23 stimulus. The targets on the haploscope arms were moved so as to increase the accommodative stimulus and the

observer was asked to report any changes in the appearance of the target. Without exception, the observers reported that the target became clearer as the stimulus distance was first increased. When the target reached its clearest position, it was found that by further increase of the stimulus, the target again started to become blurred. By moving the target back and forth along the arm of the haploscope, the position of the target could be found to give optimum visibility of the target. When this position was found, the subject was asked to align the slits in order to obtain a measure of the state of refraction. The value of the stimulus setting at this point would correspond roughly to the settings given for the measurements of the so-called "nocturnal myopia."

The average values are plotted in Figure 8. The average value of the state of refraction while observing the blob is within experimental error constant for the luminances measured. This does not agree with the earlier data taken with a group of subjects of comparable size, but does agree with the data obtained with subjects CS and HAK.

The refractive state while observing the targets was higher at all luminances when measured with the blurred slit technique than that measured with the vernier slit method, and the increase was greater as the luminance level was reduced. This may be taken as evidence that spherical aberration did tend to raise the refractive state of the eye as the luminance level was reduced. Further evidence for this conclusion is shown in Table II. Here are shown the stimulus values for optimum visibility as determined by four of the subjects. These values were determined by moving the targets along the haploscope arms and asking the subjects to report when the targets were clearest. Along with these data is the measured refractive state of the eye obtained by having the subjects align the slits at the setting for optimum visibility. These settings were made at 0.000306 C/M^2 .

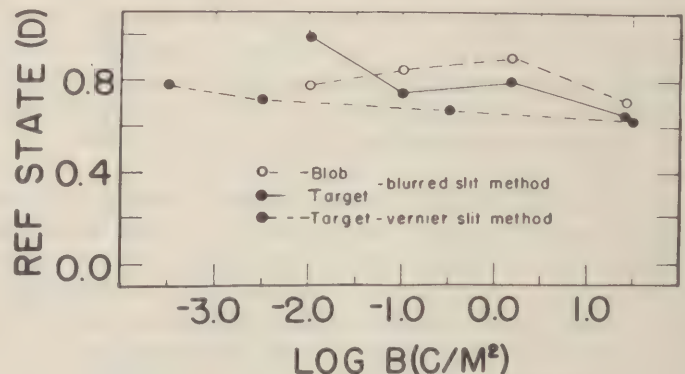


Figure 8.

TABLE II

Subject	Stimulus value of optimum visibility	Measured refractive state
WJ	1.5	1.5
NJ	1.7	0.6
RWS	1.25	0.0
HT	2.00	1.2

In all cases, the subjects reported that the targets became clearer as the stimulus level was increased. The level for each of the subjects lies somewhere between 1.0 and 2.0 diopters, the value given being the best estimate possible. The exact value was not of importance here; the important fact is that the measured state of refraction is in each case equal to or lower than the stimulus value, indicating that the refractive state of the entire pupil is not determined by the areas measured with the slits, and that the additional area must be more myopic than the area used to make these measurements.

SUMMARY AND CONCLUSIONS

A target has been constructed which has been shown to be inadequate to stimulate accommodation optically, at least over a range of approximately two diopters, starting initially at a zero stimulus. While fixating this target monocularly, the state of refraction has been determined to be approximately one diopter more minus than that determined clinically. This effect is somewhat less pronounced with binocular fixation at high levels of luminance, but the state of refraction will increase to the monocular value as the luminance of this target is reduced from a level of about 25 C/M^2 to 0.001 C/M^2 .

A target which at high levels of luminance was found to be adequate to stimulate accommodation was found to become less and less adequate as the luminance level was reduced to approximately the cone threshold. It was found at the lowest levels used that the target did not stimulate accommodation appreciably more than did the blob. This apparent reduction in the amplitude of accommodation has been called by certain authors "nocturnal presbyopia." The need for accommodation has been essentially eliminated and thus the accommodative mechanism is not fully utilized. Accommodation beyond the amount demonstrated did not improve the image quality, thus under normal conditions of low luminance seeing, ciliary action was at its resting state.

As the luminance level was decreased using a zero accommodative stimulus the refractive state of the eye increased slightly indicating that either some additional ciliary action was coming into play or that the effect of spherical aberration and pupil dilatation was causing an increase in the state of refraction. Experiments have been performed which demonstrate that some of the increase was due to ciliary action and that a part may have been due to the effect of spherical aberration and pupil dilatation.

It has been indicated that the magnitude of the so-called "nocturnal myopia" is not entirely due to accommodative changes and it is assumed that the residual effect is due to spherical aberration. That the difference was not due to chromatic aberration and the spectral shift in sensitivity was assumed since the measurements were not carried below the cone threshold.

The following conclusions can be drawn from the present work keeping in mind the foregoing results of other investigators:

- 1) In the absence of optical stimulation to accommodation, the state of refraction of the eye is higher than when an adequate zero optical stimulus to accommodation is present. This effect is greater in monocular vision than it is in binocular vision.
- 2) A stimulus, which at high levels of luminance is an adequate stimulus to accommodation may become less and less adequate as the luminance level is reduced.
- 3) These effects may be assumed to be related since the two situations are similar in that changes in the accommodative mechanism do not increase the visibility of the respective targets.
- 4) The increase in the state of refraction in these situations brought about by ciliary action can be explained in terms of parasympathetic activity. In this manner, the increased accommodation is explained as a "posture" assumed by the accommodative mechanism in the absence of adequate stimulation to accommodation.
- 5) The increase in state of refraction at low levels of luminance not accounted for by ciliary activity may be assumed to be the result of the dilatation of the pupil exposing the more myopic zones of the lens.

6) This explanation of the increased refractive state of the eye at low levels of luminance would explain the large range of values found for the magnitude of "nocturnal myopia" reported in the literature. A relatively fixed amount of the myopia could be explained by the effects of spherical and chromatic aberration, whereas the remainder would be the result of ciliary activity. The individual variations in the last named cause would account for the large variations reported by the different investigators.

7) Whatever the cause of the "nocturnal myopia," vision at low levels of luminance could be improved by the use of minus corrections and it is suggested that individuals required to perform tasks at low levels of luminance be examined for and fitted with this aid to night vision.

8) There is a reduction in the apparent amplitude of accommodation at low levels of luminance and at the lowest level measured in this study the amplitude is reduced to almost zero. This weakens Ivanoff's explanation of "nocturnal myopia" since it requires that the eye be able to accommodate in response to optical stimulation at low levels of luminance.

9) This study raises the question as to what constitutes an adequate optical stimulus to accommodation. The question applies to peripheral vision as well as to foveal vision, since the entire problem of rod vision has not been touched upon in this study.

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DEVELOPMENT OF A MESOPIC TEST OF NIGHT VISION PERFORMANCE*

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The present research program deals with a problem which has had considerable attention by various members of this committee, as well as the committee as a whole - namely, the measurement and evaluation of night visual ability. Because of continuing Army operational requirements, research geared to current needs in this area is being pursued. It will be our aim in this paper to highlight some of the more novel aspects of our present approach. In carrying out this program, we are very grateful to the working group, selected from the Vision Committee, consisting of Dr. H. Richard Blackwell, Dr. Louise Sloan, Dr. Austin Riesen and Dr. Parker Johnson, Chairman, for their able advice and guidance.

The recent history of research on night vision testing has been well summarized in the Berry Report.¹ Scientific interest in the military aspects of night vision testing received considerable impetus during World War II, in response to the surprising proficiency of the enemy in night combat. Many studies were carried out, investigating such problems as the reliability of night vision tests, the intercorrelations between different tests, and their validity in reference to outdoor criteria. By the end of the war, night vision tests were used to some extent by the Army, Navy and Air Force. Several of these tests are illustrated in Fig. 1-4.

The present program explores the possibility of substituting a measure of mesopic acuity for the usual test of low scotopic acuity. At mesopic brightnesses, which range, according to some estimates, from 5.5 to 8.0 log micromicrolamberts², the rods and cones may be operating with about equal effectiveness. Tests have been constructed for use at 5.57, 6.67, and 8.12 log micromicrolamberts to cover this mesopic range.

In undertaking the current research, we have taken the viewpoint that the chief difficulties involved in night vision testing are operational in nature, although other problems should not be overlooked. From the operational point of view, intermediate brightness tests involve shorter adaptation time (and hence more rapid testing), less dependence on light-tight testing conditions, and fewer testing personnel--factors resulting in a more economical ability assessment procedure. In the practical military situation, these advantages might well be critical in determining whether or not a test of night vision could be adopted for extensive use.

Consideration of the conditions under which soldiers perform at night lends support to

*The contents of this paper reflect the opinions of the authors and do not necessarily represent the viewpoint of the Department of the Army.

¹Berry, W. Review of wartime studies of dark adaptation, night vision tests and related topics. Ann Arbor, Vision Committee Secretariat, University of Michigan

²Dimmick, F. L. Visual acuity at low levels of illumination. Minutes and Proceedings of the Armed Forces-NRC Vision Committee. 23rd meeting, March 1949, 79-85.

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the belief that validity of mesopic tests should not be appreciably lower than the validity of scotopic tests. It is known that night brightness, during part of the lunar cycle, is above the cone threshold. In the darker phases of the cycle, the unshielded moon and stars will prevent complete adaptation to the brightness of terrestrial objects viewed. Military personnel inform us that the increasing use of artificial illuminants and pyrotechnics must also be taken into consideration in assessing the brightness of battle areas.

An interesting theoretical rationale for mesopic testing has been suggested by Dr. Blackwell. He has found that, at low intensities, the cones work like rods, in terms of the cortical signals they give. At such illuminations, spatial summation, for example, is found in the fovea, as well as in the peripheral retina. If the important aspect of the problem is considered to be the interpretation of diffuse information, an indication of this ability may be gained from foveal observations at low intensities.

It has been found that visual acuity scores among various levels of illumination are correlated. A low but positive correlation has been found between scotopic and photopic acuity³ and even higher correlations have been found between scotopic and mesopic acuity⁴. These findings, the results of studies carried out in our laboratory, will be discussed later.

The crucial measure of the success of a mesopic test lies in its ability to predict actual night performance. Present plans call for a validation study, in which the mesopic test developed will be assessed against an acceptable criterion of night vision tasks. In this phase of the program, the ability of the test to predict performance on military night visual tasks

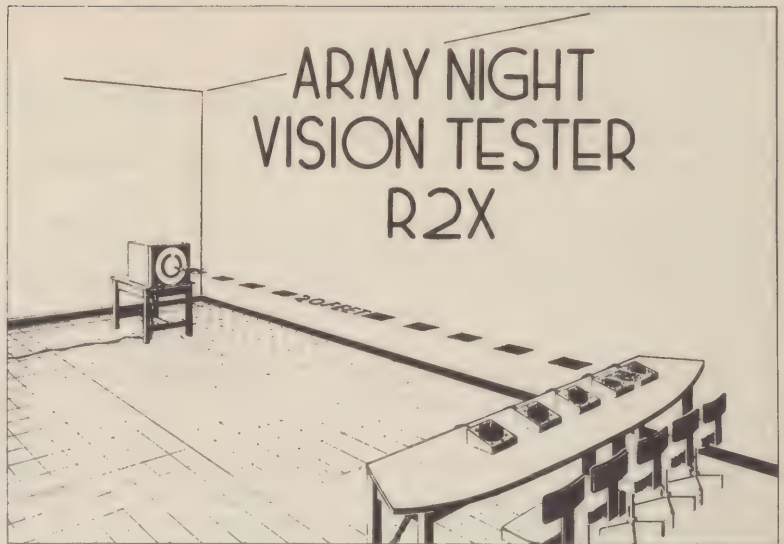


Figure 1.



Figure 2. The Navy Luminous Plaque Adaptometer

³Uhlaner, J. E. and Woods, I. A. Studies in night visibility. Highway Research Board, Bulletin No. 43, 1951.

⁴Uhlaner, J. E., Gordon, D. A., Woods, I. E. and Zeidner, J. A study of the relationship between scotopic visual acuity and acuity at photopic and mesopic brightness levels. (Article to appear in a current issue of the Journal of Applied Psychology).

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will be appraised.

Research carried out in the PRS laboratory, preliminary to the present program, explored the interrelationships among acuities at various light levels, to determine whether performance could be predicted from one level to another. The first study was concerned with the relationship between photopic and scotopic visual acuity. The photopic brightness was 10.60 log micromicrolamberts, the scotopic brightnesses, employed in the Army Night Vision Tester, ranged from 3.51 to 5.26 log micromicrolamberts. Two hundred soldiers were tested on both levels, at the PRS Pentagon Vision Laboratory. Results of this study are shown in Fig. 5. The correction for attenuation was made on the basis of the reliability of the photopic variable.

A positive correlation is found between the measures of photopic and scotopic acuity. The correlations are not high enough to permit adequate measurement of night vision ability by a day vision test, although, in the absence of any other information, selection based on a photopic test may have some value.

The finding of a positive relationship between photopic and scotopic vision led logically to the surmise that night vision ability might be very effectively predicted from acuities at mesopic brightness levels. To investigate this point, a pilot study of the relationship between scotopic visual acuity and acuity at mesopic and photopic brightness levels was carried out. The scotopic measurements were made on the Army Night Vision Tester. The photopic and mesopic acuity measurements were made on wall charts and on plates presented in the Bausch and Lomb Ortho-Rater. Subjects included 19 staff members selected to show a wide range of visual acuity. These subjects had been tested on the ANVT about a year before the commencement of the present study. Results are shown in Figs. 6 and 7.

Best eye "A" (Fig. 7) is defined as scores on the eye which gave best acuity on the majority of brightness levels tested. Best eye "B" is defined as the eye which gave highest scores on the particular level. These scores represent responses to a monocular letter plate. The binocular scores represent responses to two other letter plates.



Figure 3. The S.A.M. Test



Figure 4. Target of the AAF Tester

It was concluded that scotopic acuity scores show moderate positive correlations with photopic acuity scores, and higher correlations with mesopic acuity scores. This result is shown both for the alley chart and Ortho-Rater tests.

High correlations with mesopic acuity were obtained in this study, even though the scotopic test was administered to the subjects a full year before administration of the photopic and mesopic tests. This finding tends to indicate that scotopic visual acuity scores are stable enough to allow their long term prediction.

The high intercorrelations among acuity scores taken at different levels of illumination strongly indicated to us the feasibility of developing a mesopic test of night vision performance. The program formulated aims at setting up a field criterion, acceptable to technical and military personnel, and evaluating a set of Ortho-Rater targets against this criterion. To justify acceptance, the mesopic test should have validity of sufficient magnitude for effective prediction and superior to that demonstrated by photopic tests. Carrying out this program involves essentially the following steps:

A. The development of an optical instrument suitable for visual measurement under mesopic brightness levels.

B. The development of appropriate targets for this instrument.

C. Standardization of the procedure of test administration.

D. Development of an acceptable criterion for a validation study.

E. Determining the validity of the mesopic measures in relation to this criterion.

CORRELATIONS BETWEEN THE SCOTOPIC (ANVT-R2X) AND PHOTOPIC TESTS (N = 200)

Photopic Test	Test-Retest Reliability	Correlation with ANVT-R2X	Correlation ANVT-R2X Corrected for Attenuation
Modified Landolt Ring	.80	.35	.39
Army Snellen	.88	.38	.40
Line Resolution	.85	.39	.42
Quadrant Variable Contrast	.57	.21	.28
Dot Variable Contrast	.43	.19	.29
Checkerboard Variable Grid	.81	.29	.32
Ortho-Rater (far)	.87	.27	.29
Ortho-Rater (near)	.82	.25	.27

Figure 5.

CORRELATIONS OF ANVT-R2X SCORES WITH WALL CHART SCORES TAKEN AT 7 BRIGHTNESS LEVELS (N = 15)

Brightness Level (log μ L)	Modified Landolt	Army Snellen	Line Resolution
10.60	.58	.42	.35
9.51	.61	.44	.12
8.96	.59	.47	.53
7.94	.69	.56	.48
7.33	.60	.57	.65
6.94	.62	.61	
6.51	.81		

Figure 6.

CORRELATIONS OF ANVT-R2X SCORES WITH ORTHO-RATER SCORES TAKEN AT 8 BRIGHTNESS LEVELS (N = 16)

Brightness Level (log μ L)	Best Eye "A"	Best Eye "B"	First Binocular	Sloan Binocular
10.18	.18	.31		.12
9.51	.59	.59		.12
8.96	.63	.65	.40	.21
7.85	.68	.75	.54	.38
7.29	.49	.57	.40	.22
6.96	.22	.21	.51	.43
6.51			.43	.33
6.03				.35

Figure 7.

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The first step in the program, "the development of an instrument suitable for measurement under mesopic brightness levels," involved adapting the Ortho-Rater for use in mesopic testing. It was considered that the Ortho-Rater had obvious advantages, over wall chart presentation, in control of illumination and viewing distance, ease of administration, and economy of testing space required. The instrument was planned by Dr. Blackwell and constructed under his direction.

The brightness of the visual field of the modified instrument has been made uniform, by interposition of a corrector photographic plate of varying density between the light source and the stimulus target. This plate also serves to insure that the proper standard test level of 12.0 foot lamberts is obtained. A constant voltage transformer, in series with the light source, stabilizes the 110-volt output between input levels of 68 to 127 volts. A photometric device has been installed which permits standardization of the brightness of the visual field. This device consists of a photometric comparator and a standard source which allows calibration of brightness in a manner somewhat similar to that used in the Macbeth Illuminometer. Reduction of the luminance of the light screen to the required mesopic and scotopic levels is effected with pairs of Wratten gelatine filters. These filters are mounted in a special eyepiece, so that stray light cannot leak around them. The light level can be reduced, by introduction of these filters, from 12.0 foot lamberts to the desired mesopic light levels mentioned earlier. These modifications make the instrument a more suitable one for the testing of photopic acuity, as well as mesopic and scotopic acuity.

With the construction of the modified Ortho-Rater, the groundwork was laid for carrying out the remaining projects in the program. Among the problems is the development of mesopic Ortho-Rater plates. These plates are being made from wall charts by photographic reproduction. The targets will test the visual functions of retinal resolution and brightness contrast. Retinal resolution requires the discrimination of fine details, brightness contrast requires discrimination of a difference in brightness between two relatively large surfaces. These factors have been found in an earlier PRS factor study⁵ to explain the variance of photopic visual acuity.

A preliminary tryout of several mesopic plates has been carried out on 117 soldiers in the laboratory. These men were tested, and then retested two weeks later on the same targets. Four types of visual acuity tests were employed - a letter test, a checkerboard grid design, a modified Landolt Ring, and a line resolution chart.

These tests are now being revised, employing methods of item analysis, to give increased discrimination and reliability. Increased reliability may also be expected when the tests are administered on the Blackwell Ortho-Rater.

An incidental finding of this study was that Ortho-Rater plates show higher reliability than duplicate wall charts at a photopic level. At the mesopic level, the results are not so clear cut, as rigid control of stimulus conditions was not attained.

Several brightness contrast tests are also being constructed. Accurate photographic reproduction of varying contrasts required in such tests has been attained. The charts constructed, employ various concentrations of uniformly thick lines. When presented at a distance, these lines fuse to a uniform gray surface. The reflectance of the chart surface may be controlled by varying the number of lines per unit of surface.

The brightness contrast designs and several other mesopic target designs are illustrated in Fig. 8. The chevron contrast test requires the subject to give the orientation, up,

⁵Staff, Personnel Research Section, The Adjutant General's Office. *Studies in visual Acuity*. U. S. Government Printing Office, Washington: 1948.

down, right or left of the point of the chevron. The subject's perception of the contrast difference between background and stimulus is indicated by his identification of the direction in which the chevron points.

The other contrast design requires an even simpler response. A circular spot varying in brightness is presented in any three of six positions along the chart. Subjects are required to scan each line and to state for each position whether or not the spot appears.

In standardizing the procedure of administering the tests, an important problem is the determination of the minimal period of dark adaptation required for mesopic testing. The traditional dark adaptation function does not apply; the present problem is geared to particular operational conditions. The concern is with the dark adaptation time required by a soldier who is taken from a well lit waiting room, dark adapted in a more or less light-tight room, and examined with acuity targets administered at a mesopic brightness level. The experiment, in line with these requirements, employs a pre-adaptation brightness of 100 foot lamberts. The dark adapting brightness is at the testing levels themselves. At adapting levels higher than the testing levels, adaptation to the testing levels will never occur. At lower brightnesses, an over-estimate of the time required for operational testing will be made.

As is obvious, the dark adaptation function plotted for these conditions differs from the classical curve. Preliminary experimentation carried out in our laboratory shows that terminal acuity involves perception of a target of about half the visual angle of initial acuity. The initial observation is taken after about 20 seconds in the dark. Almost complete dark adaptation to the 6.67 log micromicrolambert mesopic level is attained in 10 minutes. These results, which can only be regarded as tentative, are being checked in intensive experimentation on a large group of subjects by Mr. Joseph Zeidner of our laboratory.

The object of this study is to select a dark adaptation time which gives reliable measures for even the slow adapting individual. An analysis is also being made of the sources of individual differences in the dark adaptation function.

In the final project of this program, the validity of the mesopic tests will be determined against an appropriate criterion of night vision ability. Soldiers, or appropriate manikins will be used for validation targets. Infantrymen who have been in combat in Korea have informed us that the enemy soldier is the most critical and most difficult target to see.

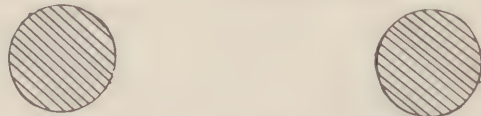
The criterion course will consist of targets set up at various distances from central viewing stations situated on high ground. Soldiers would be individually tested in separate booths. They would be asked to identify such objectified items as the position, garb and

P L O E

Mesopic New Army Snellen



Modified Landolt ring



Spot brightness contrast test



Chevron brightness contrast

Figure 8. Designs of mesopic acuity tests

movement of the targets. A composite score, based on these sub-scores, would be computed for each man.

Another type of criterion course being considered may consist of targets mounted on moving carts. The targets would be prepared for presentation in concealed positions at either end of the viewing area, and moved across on a line parallel to the subjects. The viewing area would have a uniform background. Scoring on this criterion would be similar to that of the one previously described.

In summary, a program for development of a mesopic test of night vision ability is being undertaken by the Personnel Research Section. The targets will be presented in an Ortho-Rater, modified for mesopic use by Dr. Blackwell. Ortho-Rater plates testing the acuity factors of retinal resolution and brightness contrast are being constructed. Plans are being made for determining the dark adaptation period required for mesopic testing under operational conditions. The validity of the tests will be determined against an appropriate criterion of night vision performance.

Discussion:

- Dr. Rose reported that in Germany during the last war attempts were made to replace scotopic acuity tests by mesopic tests. Specifically, an instrument was devised which measured visual acuity after three minutes in the dark. This attempt was abandoned. Although positive correlations were found between scotopic and mesopic visual acuity, it was found impossible to screen out the deficient individuals and to select good night fighters with the mesopic test.

- Dr. Uhlaner commented on Dr. Rose's remark by emphasizing that the AGO is not interested so much in screening those with defective or superior night vision as in classifying infantrymen as to their relative capacity for night seeing. In a combat zone, unit commanders are anxious to have information available on the spot to assist them in assigning men to night duty. The AGO has no intention of eliminating night vision testing, particularly for the purpose of screening those with defective night vision.

- Dr. Uhlaner remarked that the AGO had also found positive correlations between scotopic and photopic tests and that this information is being used in the development of the mesopic tests.

- Dr. Sloan questioned the use of the term "Orthorater" for the revised vision tester, pointing out that this is a trade name rather than a generic term for a class of tests.

- Dr. Uhlaner agreed that the term was somewhat unfortunate and suggested that the AGO would welcome alternative suggestions.

EFFECT OF FLASHES OF LIGHT ON NIGHT VISUAL ACUITY

PART I

Glenn A. Fry and Mathew Alpern
Ohio State University Research Foundation

INTRODUCTION

The purpose of this study is to find out the ability of the eye to see a dark object against a sky background at night after the eye has been exposed to a flash of light, or a series of flashes. In this study the pattern illustrated in Fig. 1 has been used to measure the ability of the eye to see. Using his right eye only, the subject looks at the red fixation point (A) and this brings the test object (B) to fall 5° to the right of the principal line of sight. B is a disc having a brightness in most of the experiments equal to 0.0107 millilambert and when such a surface is viewed through a 2 mm. artificial pupil, as was the case in the experiments to follow, the retinal illumination (0.107 troland) is equivalent to that produced by a moonlit sky. The black bar extending vertically across the center of the disc can be varied in width to measure the threshold of visibility. By this method it is possible to measure the sensitivity of this part of the retina while keeping it exposed to a constant background brightness.

If a flash of light directly stimulates that region of the retina which is to be tested, it will affect directly the adaptation of the photoreceptors in that region, and in order to investigate the effect of such a direct exposure the following procedure was used. While the eye fixated the point A, the disc-shaped area (B) had superimposed upon it a patch of brightness of the same size and shape as B and then, while the eye continued to fixate A, recovery of the stimulated area of the retina was studied by measuring the threshold width of the black bar.

The brightness and duration of these flashes have been investigated, and also the effect of using a multiple number of flashes. An attempt has also been made to evaluate the performance of the eye at lower levels of background brightness than 0.01 millilambert.

Under the conditions of this type of experiment, the exposure of the eye to a flash patch not only impairs the capacity of the photoreceptors to respond to subsequent stimulation but also produces a positive after-image. A complete understanding of the effect of a flash of light cannot be claimed until the role played by this positive after-image is taken into account. When the flash patch is exactly the same size and shape as the test patch, it might be questioned whether small eye movements which cause a fresh portion of the retina to receive a portion of the image of the test patch might affect the results. Consequently, exploratory experiments have been undertaken with much larger flash patches to investigate the role played by this factor.

When the flash patch falls in a different part of the field than the test patch, one of the obvious ways in which the test patch can affect the subsequent response of the eye to the bar is for stray light from the flash patch to cover the region of the retina in which the test patch falls. This adapts that region of the retina to a level of retinal illuminance represented by the stray light. If the effect of a flash patch which does not coincide with or overlap the test patch can be accounted for in terms of stray light in the eye, then the effect of a given distribution of light in a flash in the visual field could be evaluated without

an empirical investigation of all the possible brightness distributions which might occur. In order to explore this possibility, flash patches at various distances from the test patch have been used; the effect of area of the test patch has also been investigated as well as the effect of placing the flash patch on the blind spot.

In all of this work, the size of the beam entering the eye has been restricted by artificial pupils which are smaller than the natural pupil, so that variations in the size of the natural pupil have not influenced the results. There are changes in pupil size which occur as a result of a flash of light, but it was decided to study these effects in a separate investigation which will be described in another report.

APPARATUS AND PROCEDURE

A. Head Supports

The subject's head was supported by a forehead support and biting board which could be adjusted to put the center of the entrance pupil of the right eye at the point E, in Fig. 3, when this eye is fixating the red fixation point at A₁. Sighting devices not shown in the figure were used in making this adjustment.

B. The Fixation Point.

Light from the small bulb S₁ passes through a red filter and the pin-point aperture A₁, then strikes the small mirror M₁ and is reflected so as to strike the peripheral region of the lens L₁ in such a way that the image of A₁ is seen approximately 5° from the center of the lens L₁ by the right eye of the observer placed with its entrance pupil at the point E. The intensity of the fixation point can be controlled by a rheostat. The mirror image of A₁ falls in the plane of the aperture A₂.

C. The Visual Acuity Measuring Device

The visual acuity target, T, is a vertical black line on a piece of white cardboard, which is illuminated by two line filament sources S₂ the intensity of which can be varied by a rheostat. Considerable care has been exercised in the design of the form of the sources S₂ and their positions with relation to the target in order to maintain uniform illumination on the target. The vertical line filaments of the two sources are long enough so that one can assume that these sources are equivalent to two luminous lines indefinitely extended. Consequently, one can assume that the illumination is constant at points on any given vertical line across the target. Assuming that the two luminous lines are indefinitely extended the illuminance (I) in foot-candles at any given point P at a distance v from the perpendicular line through the center of the target is as follows:

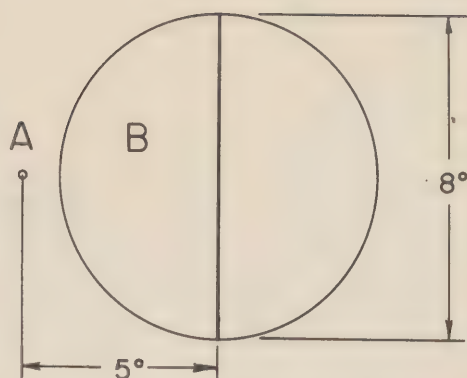


Figure 1. Peripheral Test Object and Fixation Point Used for Measuring the Ability of the Eye to See a Dark Object Against a Sky Background.

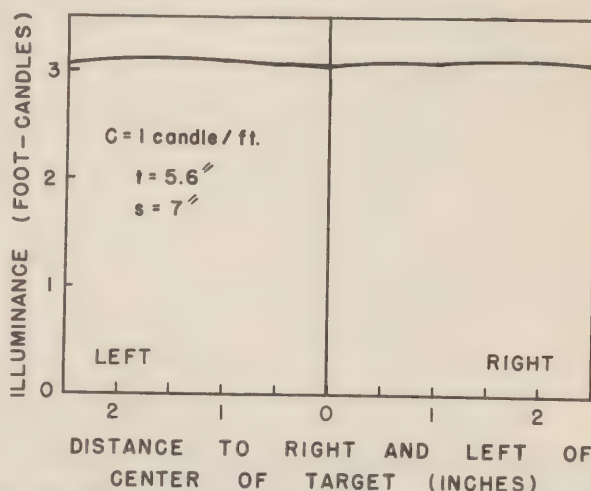


Figure 2. Distribution of the Light Illuminating the Target.

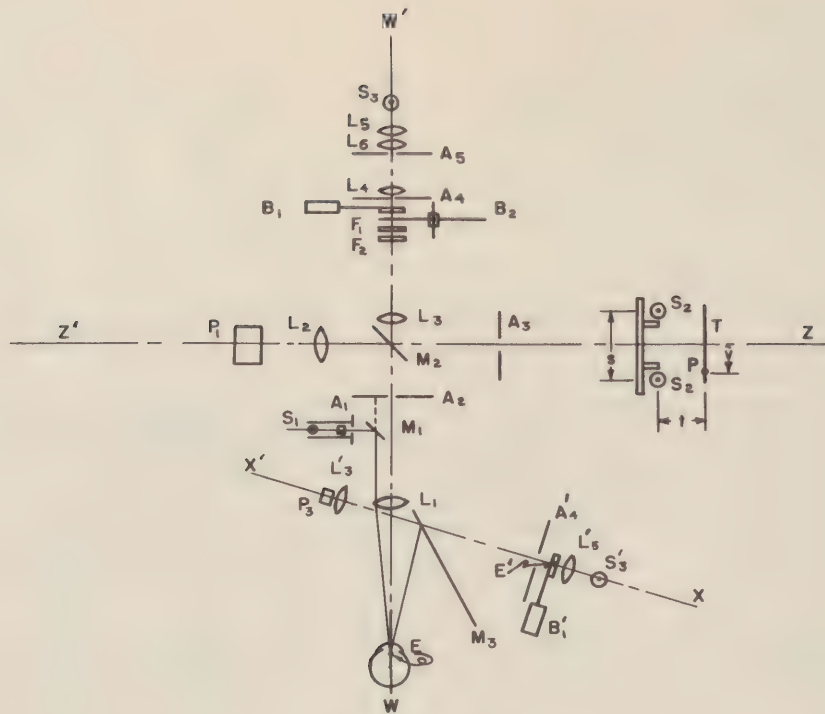


Figure 3. Apparatus

$$I = 4 Ct \left[\frac{1}{t + \left(\frac{s}{2} + V \right)^2} + \frac{1}{t + \left(\frac{s}{2} - V \right)^2} \right] \quad (1)$$

where s represents the distance between the two sources, and t represents the perpendicular distance of each source from the screen and C represents the candlepower per foot of filament length, and where all distances in the equation are expressed in feet. Fig. 2 shows the distribution of illuminance along the horizontal diameter of the disc when $C = 1$ candle per foot, when $s = 7$ in. and $t = 5.6$ in. The target and two sources are all mounted on a trolley which moves along a track, which keeps the target centered on the axis ZZ' . Light from this target passes through the aperture A_3 above the mirror M_2 to the lens L_2 . After passing through the lens L_2 the light passes through the Porro prism P_1 to be reflected by the semi-silvered mirror M_2 . The Porro prism is also mounted on

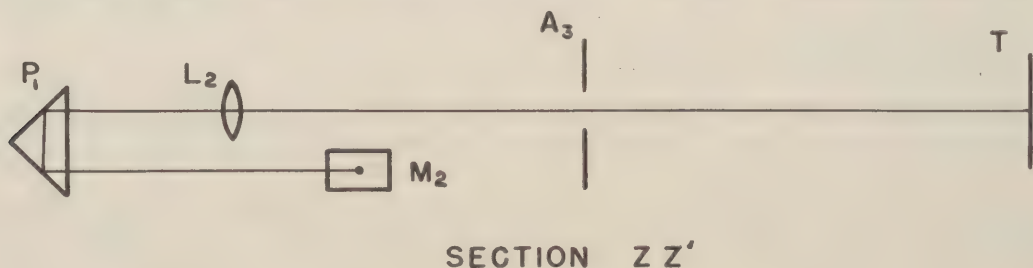


Figure 4. A Vertical Section Showing Part of the Apparatus in Figure 3.

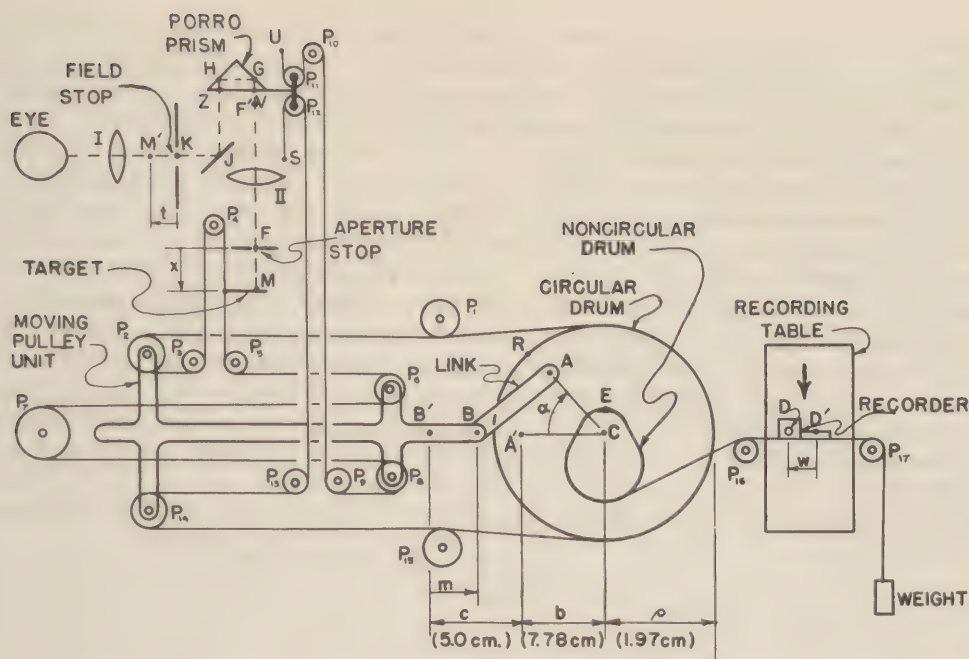


Figure 5. Mechanism for (1) Changing the Visual Angle Subtended by the Bar and (2) Recording the Data.

a trolley which moves along the axis ZZ' and this movement is synchronized with that of the target by a special driving mechanism described below which is designed to keep the image of the target formed by lens L_2 in the plane of the aperture A_2 . The eye at E sees the image of the target at optical infinity and magnified to a variable degree depending on the position of the target. A vertical section of this system along the line ZZ' is illustrated in Fig. 4.

The angle subtended by the test object at the aperture A_3 is equal to the angle subtended by the image of the target as seen by the eye at E since the lenses L_1 and L_2 have the same focal length; since the distance from E to L_1 is equal to the focal length of L_1 ; and since the distance from A_3 to L_2 is equal to the focal length of L_2 . This relation simplifies the computation of the angular size of the image of the bar at the entrance pupil of the eye.

The driving mechanism designed to synchronize the movement of the target and the Porro prism is shown in Fig. 5. In this figure the target M corresponds to the target T in Fig. 3. The aperture stop F corresponds to aperture A_3 , the Porro prism corresponds to the Porro prism P_1 , the field stop K corresponds to the aperture A_2 , the mirror J corresponds

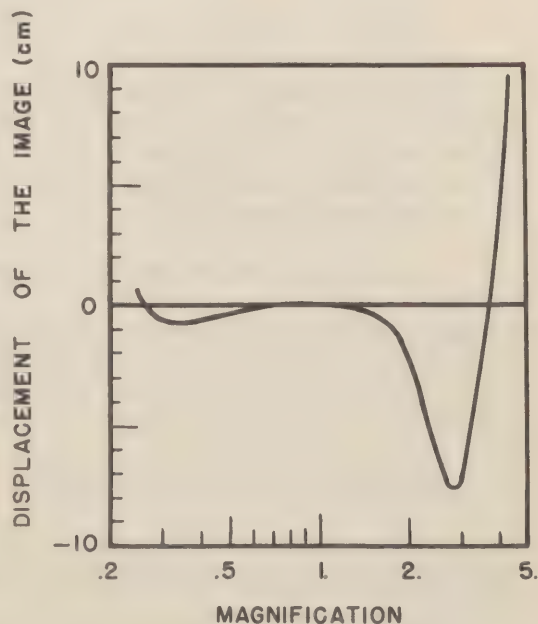


Figure 6. Extent to Which the Image M' is Displaced in front of (+) or Behind (-) the Plane of the Field Stop, K .

to the mirror M_2 and the lenses I and II correspond to L_2 and L_1 . The pulleys P_4 , P_3 , P_5 , P_7 , P_{13} , P_{10} , P_9 , P_1 and P_{15} are mounted on axles which are fixed to the instrument. Pulleys P_2 , P_8 , P_6 , and P_{14} are mounted on axles fixed to the moving pulley unit. Pulleys P_{11} and P_{12} are mounted on axles which are fixed to the trolley carrying the Porro prism. The position of the Porro prism is controlled by means of two flexible cables. One of these cables wraps around P_{12} and connects the point S, which is fixed with respect to the instrument, with the point R on the circular drum. The second cable wraps around pulley P_{11} and connects the fixed point U with the point R on the circular drum. The target M is connected to the flexible cable which connects the point U with the point R. The circular drum is mounted on a shaft which is geared to a crank controlled by the operator. When this circular drum moves in a clockwise direction through an angle α , it takes up a certain amount of the flexible cable UR and releases the same amount of the cable SR. The link which connects the eccentric point A on the circular drum to the point B on the moving pulley unit moves the point B on the moving pulley unit through a distance m from its starting point B'. The driving mechanism is designed to keep the image M' of the target M in the plane of the field stop K, but the compensation is not perfect and the displacement (t) of M' from K is finite and found by means of the following equation:

$$t = \frac{f^2}{f + 2m - \epsilon a} - (f + 2m + \epsilon a), \quad (2)$$

where

$$f = \text{focal length of lens II} \quad (3)$$

and

$$m = b [\cos \alpha + \sqrt{(\frac{c}{b})^2 - \sin^2 \alpha}] \quad (4)$$

Defining magnification ϕ as the ratio of the width of the image of the bar at M' to the width of the bar at M,

$$\phi = -\frac{f}{x} = -\frac{f}{f + 2m - \epsilon a} \quad (5)$$

Fig. 6 shows the amount of displacement t of M' from K for various values of ϕ .

The field stop K limits the field of view to a circular patch 8° in diameter. The image of the target completely fills this aperture and the dark vertical line through the center of the target appears as a dark vertical bar through the center of the aperture stop giving the appearance shown in Fig. 1. The angular width of this bar at the eye is given by the following equation:

$$\text{Visual angle subtended by the bar at the eye in radians} = \frac{y}{x} \quad (6)$$

where y represents the width of the black line on the target at M and x represents the distance of the target from the primary focal plane (F) of lens II which is also the aperture stop. All of the data presented in this report except those dealing with low background brightnesses were obtained with a black line 0.5 mm wide.

D. Flash Patch Exposure Devices.

There are three flash patch exposure devices, two of which will be described here and one later in connection with large flash patches.

Device No. 1. This device provides for a flash patch of the same size and position as the test patch. Light from the ribbon filament source S_3 in Fig. 3 is brought to a focus with the lenses L_5 , L_6 and L_4 at the aperture A_4 and after passing through the neutral density filters F_1 and F_2 is collimated by the lens L_3 , passes through the semi-silvered mirror M_2 , the aperture A_2 , and is then brought to focus at the center of the entrance

pupil of eye E by the lens L_1 . The field stop A_2 is also the field stop for the test patch, and consequently the size of the flash patch is the same as that of the test patch. The brightness of the test patch is controlled by means of neutral density filters (F_1 and F_2). The aperture A_4 is 1 mm in diameter and constitutes the aperture stop for the flash patch. An image of the aperture is formed in the plane of the entrance pupil by the lenses L_3 and L_1 . This image in the plane of the entrance pupil has the same size as the aperture stop itself. The time of onset and duration of exposure of the flash source is regulated by means of a shutter device which is partly mechanical and partly electromagnetic. It provides exposure durations of 1, 3, 10, 30, 100, 300, 1,000 and 3,000 milliseconds and longer were provided by the electromagnetic part of the shutter which consists of a solenoid with two coils one of which opens the shutter and the second of which closes the shutter. The solenoid coils are controlled by micro-switches activated by cams driven by a constant speed motor. A single manual switch is pushed to turn on the light source S_3 and to start the motor which drives the cams. A second switch is pushed which, when the timing mechanism is first ready after the switch is pushed, gives one complete exposure.

Exposures as short as and shorter than 30 milliseconds are obtained by means of a rotating sectored disc shown in Fig. 7 which is synchronized with the timing mechanism controlling the electromagnetic shutter. It rotates 10 times per second. The electromagnetic shutter is set to give an exposure of 100 milliseconds and during this interval the rotating sectored disc provides an exposure of 30, 10, 3, or 1 milliseconds depending upon which of the open sectors crosses the beam. Each of these exposures starts 50 milliseconds after the electromagnetic shutter opens. The axis of the rotating disc can be swiveled around a second axis parallel to itself so that either one of the four open sectors can be made to cross the beam, or the entire disc can be lifted out of the way of the beam so that the electromagnetic shutter alone controls the exposure.

Device No. 2. This device provides for a peripheral flash patch which can be presented to the eye when the eye is held in position for observing the test patch, and hence one can follow through with the presentation of the flash patch and the measurement of the effect of this flash upon the visibility of the bar without changing the position of the head or the eye.

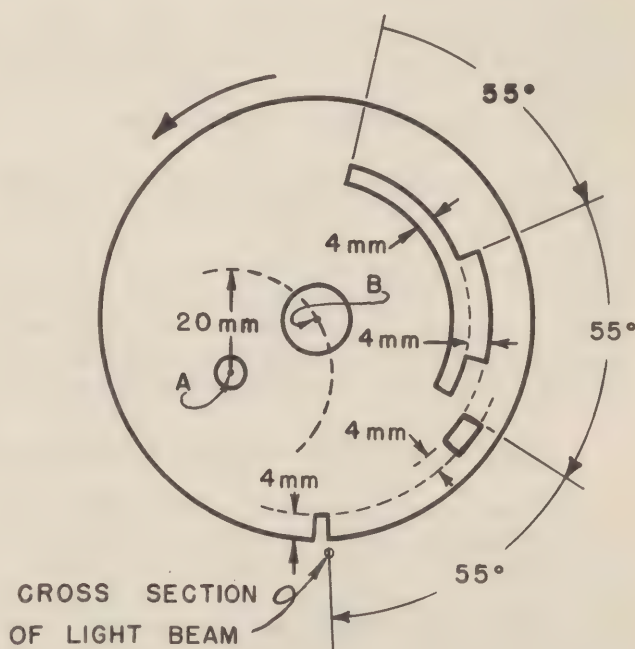


Figure 7. Rotating Sectored Disk for Producing Exposures 1, 3, 10, and 30 Milliseconds Long. The Disk Rotates 10 Times Per Second.

The mechanism for this device is more clearly illustrated in Fig. 8 which is a section view of part of Fig. 3 along the axis XX' . Light from the ribbon filament source S'_3 is focused by the lens L'_5 in the plane of the aperture stop A'_4 . After passing through the diaphragm A'_4 the light passes above the mirror M_3 , through the lens L'_3 , the Porro prism P_3 , the lens L'_1 , then after reflection at the mirror M_3 , it comes to a focus at the center of the entrance pupil E of the observer's eye (Fig. 3). The elements S'_3 , A'_4 , L'_5 , L'_3 , L'_1 , P_3 , B'_1 and A'_2 are mounted on an arm which rotates above the mirror M_3 around E' , which is the image of E formed by the mirror M_3 . This provides a means for varying

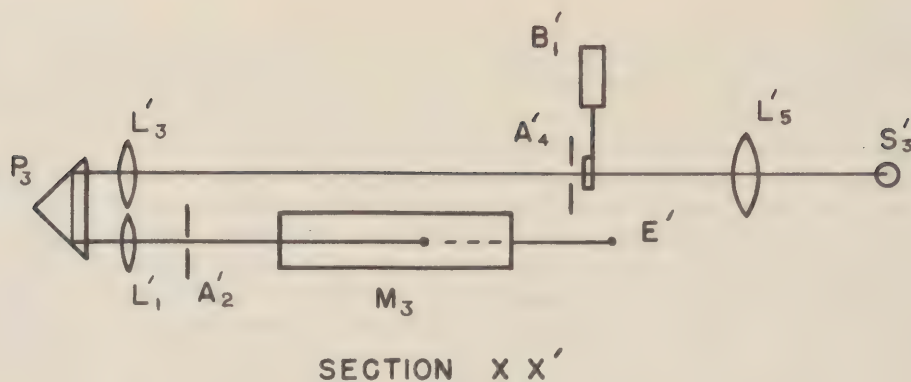


Figure 8. Vertical Section Showing part of the Apparatus in Figure 3.

the displacement of the center of the flash patch from the center of the test patch through the range from 8° to 35° , and since this is in the horizontal meridian of the right eye, it affords a unique way of studying the effect of light scattered within the eye including the effect of light striking the blind spot.

The aperture stop A'_4 is 2 mm in diameter and an image of this aperture of the same size is formed by the lenses L'_3 and L'_1 at the center of the entrance pupil.

The aperture A'_2 controls the size and shape of the peripheral flash patch. This is circular and several apertures were used providing diameters subtending visual angles ranging from 3.5° to 0.35° . The electromagnetic shutter B'_1 is identical in type with the electromagnetic shutter B_1 and its onset and duration of exposure is controlled by the same timing mechanism which provides exposures of 100, 300, 1,000 and 3,000 milliseconds.

E. Procedure in Measuring the Effect of a Flash

Preliminary to such a measurement it is necessary to adjust the headrest and the biting board so that when the subject puts his head in the instrument, the entrance pupil of the right eye will fall at the proper point. The subject is dark adapted for 30 minutes in a dark room and then he puts his head in the instrument. His attention is directed to the fixation point which he attempts to fixate steadily during the course of the experiment. Time is allowed for the subject to become bright-adapted to the level of the test spot. When the operator is ready to give the subject a flash he pushes first the switch that starts the recorder, then the switch that starts the timing mechanism and turns on the source for the flash patch, and then the switch that gives the exposure. As soon as the flash is over, he throws the switch which stops the timing mechanism and turns off the source for the flash patch and at the same time marks a line on the record, as will be explained later, which indicates the cessation of the flash. Starting with the minimum width, the width of the bar is increased until it first becomes visible. This width is recorded after which the width is then decreased until the bar becomes invisible and then is increased again until it becomes visible, the width again being recorded. This process is repeated until the threshold width reaches a stable level. The subject is then given a second exposure of a flash involving a different brightness or duration and the process of recording the effect of the flash is repeated.

If immediately after the cessation of the flash the bar is not visible when it is increased to its maximum size, it is left at its maximum size until the subject first reports it to be visible, and then the size is decreased until it becomes invisible, then increased

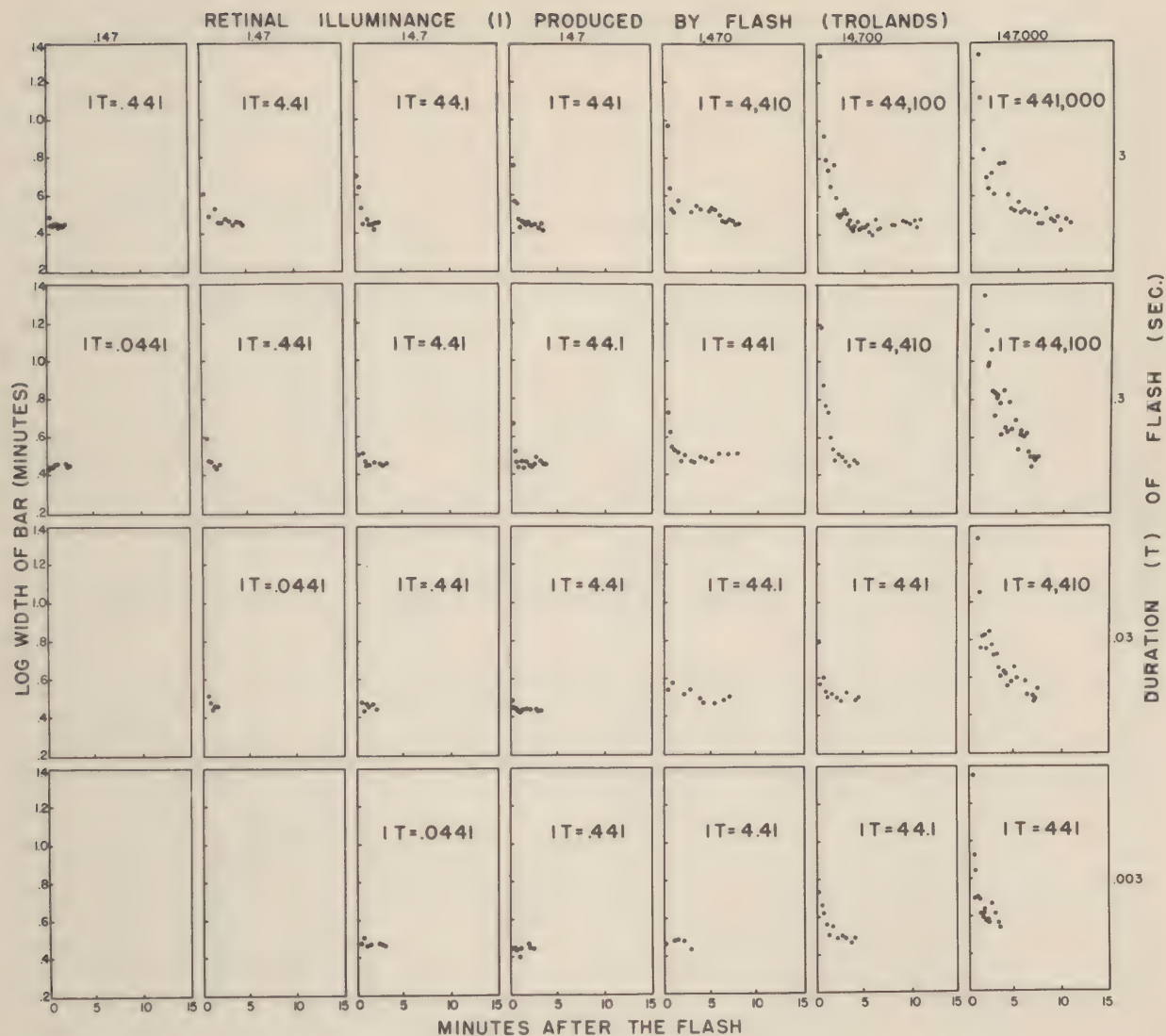


FIG. 9A

RETURN OF VISUAL ACUITY TO NORMAL
FOLLOWING FLASHES OF VARIOUS
DURATIONS AND BRIGHTNESSES THAT
ARE COEXTENSIVE WITH THE TEST
SPOT.

DATA FOR P.H.

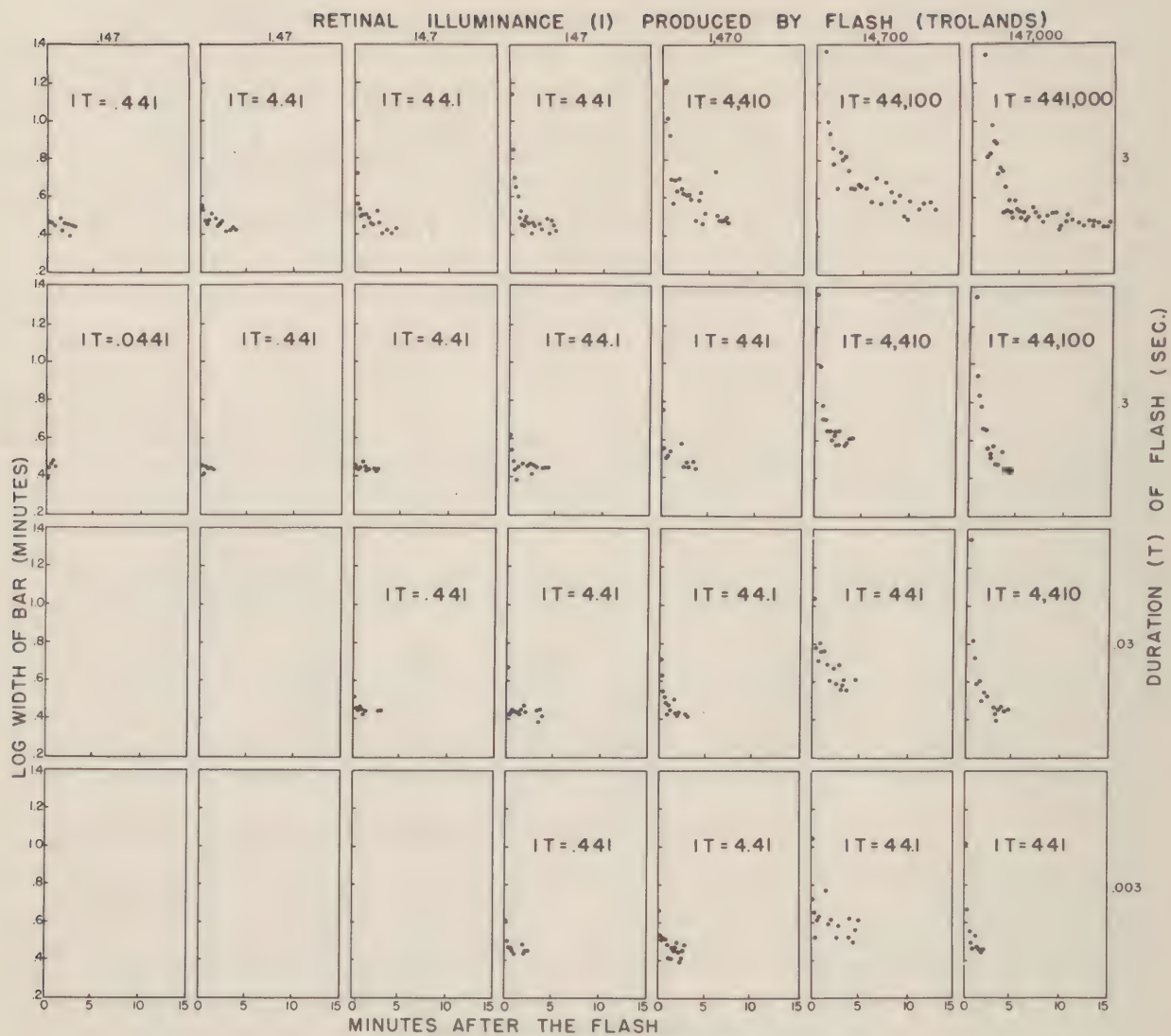


FIG. 9B

DATA FOR M.A.

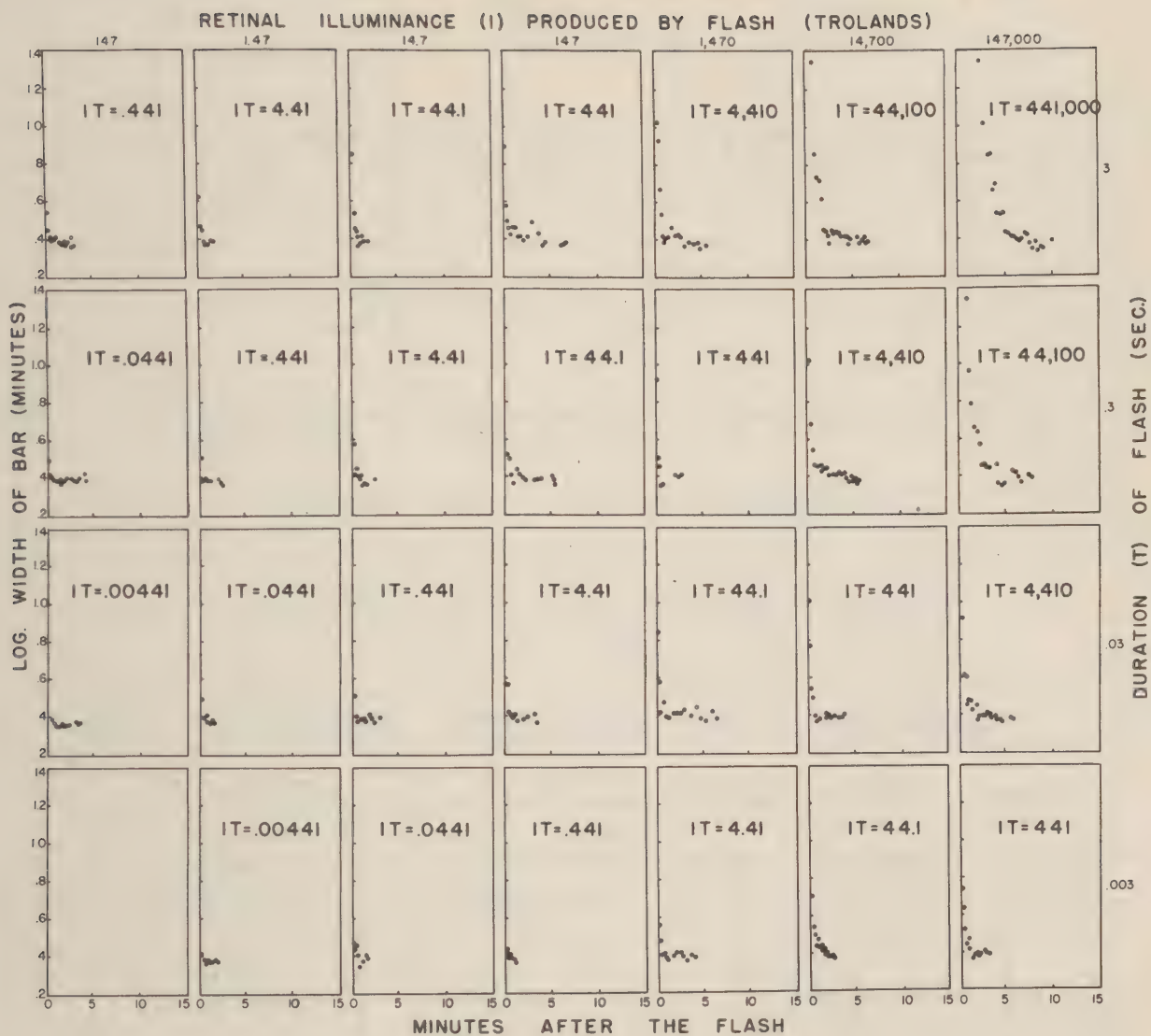


FIG. 9C

DATA FOR L. Z.

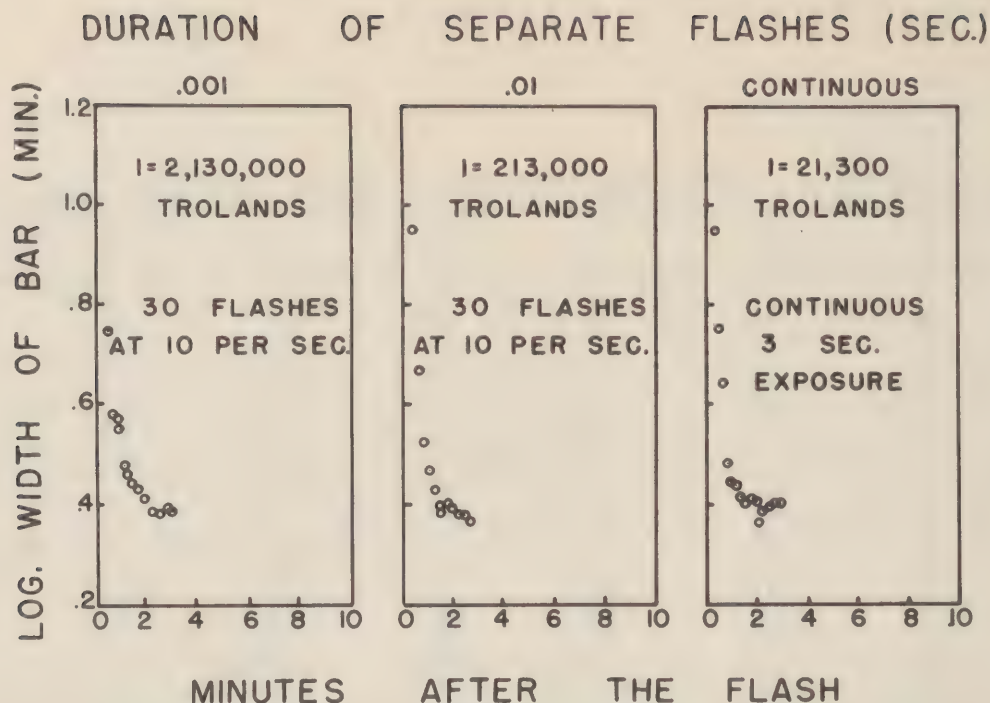
~~RESTRICTED~~

FIGURE 10A

Return of Visual Acuity to Normal Following a Series of 30 Flashes at 10 Per Second and Following Continuous Exposure for 3 Seconds.
(Subject L.Z.)

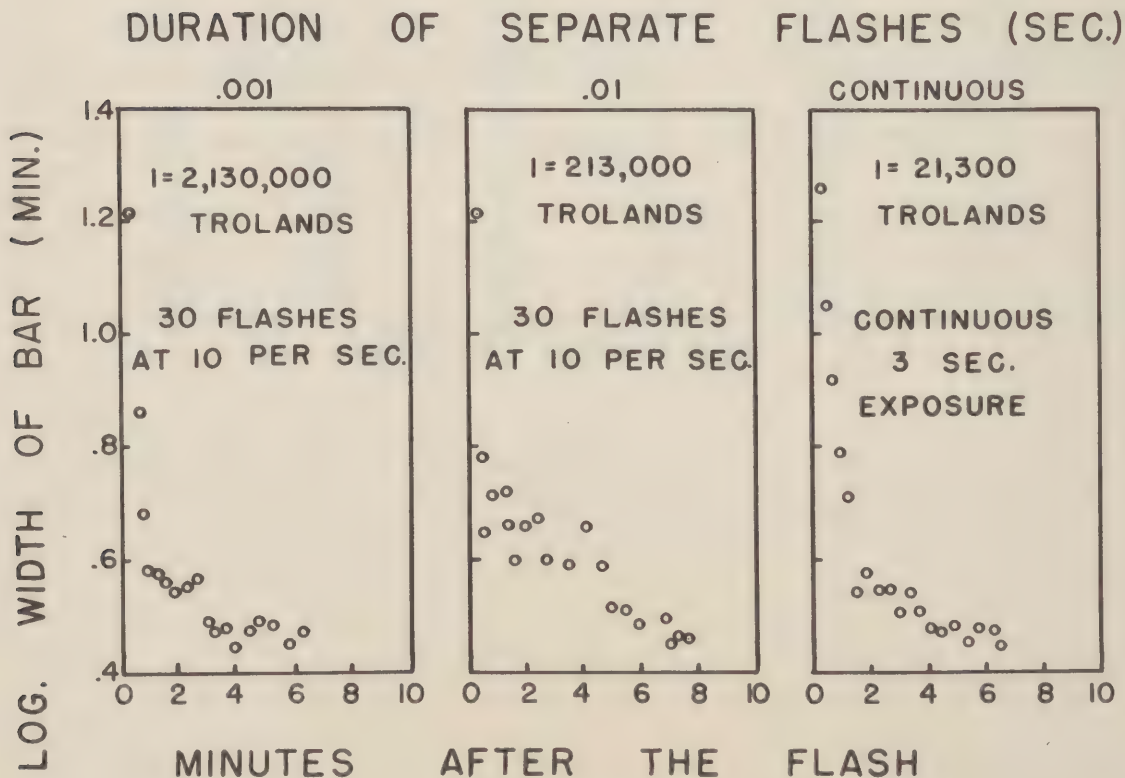


FIGURE 10B

(Subject P.H.)

~~RESTRICTED~~

again until it becomes visible; this is the threshold size that is recorded. From this point on, the procedure is the same as in the case already described.

F. The Recording Mechanism

The recording mechanism is illustrated in Fig. 5. The recording table with a piece of paper mounted on it moves in the direction of the arrow at a constant rate of 5 mm per minute. Above the moving paper is a metal plate with a small hole D through which a pencil point can be inserted to make a small circle on the record. This plate is attached to a sliding metal bar driven by the flexible cable which is held tight by the weight and is attached to the point E on the non-circular drum. This drum is mounted on the same shaft that drives the target M and the Porro prism which controls the angular size of the bar as seen by the eye. This non-circular drum is designed so that the displacement of the hole D from its starting point D' is proportional to the logarithm of the angular width of the image of the bar. A record of the position of the hole at any given moment can be made by inserting a pencil and tracing around the edge of the hole. The cessation of a flash can be indicated by drawing a straight line along the straight edge which if extended would pass through the center of the hole D.

The data for a 50-minute run can be recorded on a single sheet of paper. Hence the recording table is set in motion prior to the first exposure of the flash patch in any given experimental run and allowed to run for the full 50 minutes. If the session proves to be longer than this the operator takes time out to change to a new sheet of paper and to reset the recording table for a new run.

The graphs presented in this report, showing the return of the threshold width of the bar to normal following exposure to a flash patch, are direct tracings of the records made in the manner described above. In each graph the time scale and the scale representing the logarithm of the width of the bar have simply been added to the trace of the raw data.

Operations such as adjusting the shutter speed, changing the filters, changing the size of the bar and recording the data can all be carried out in total darkness; consequently, during the whole experiment the field of view of the subject is kept in total darkness except for the fixation point, the flash patch and the test patch. If an emergency makes it necessary for the operator to have any light, a small flashlight covered with a red filter is used, and during the time that the light is on the subject is asked to close his eyes. The operator carefully avoids pointing the flashlight at the subject.

SUBJECTS

The data included in this report were obtained from three subjects all of whom were men. Subjects M.A. and L.Z. wore their corrections and subject P.H. did not. The ages and corrections for the different subjects are given in Table 1.

Table 1

Subjects

Subject	Age	Correction (Right Eye)	
M. A.	29	+ 4.75	-1.37 x 5
L. Z.	39	+.25	- .50 x 10
P. H.	22	None	

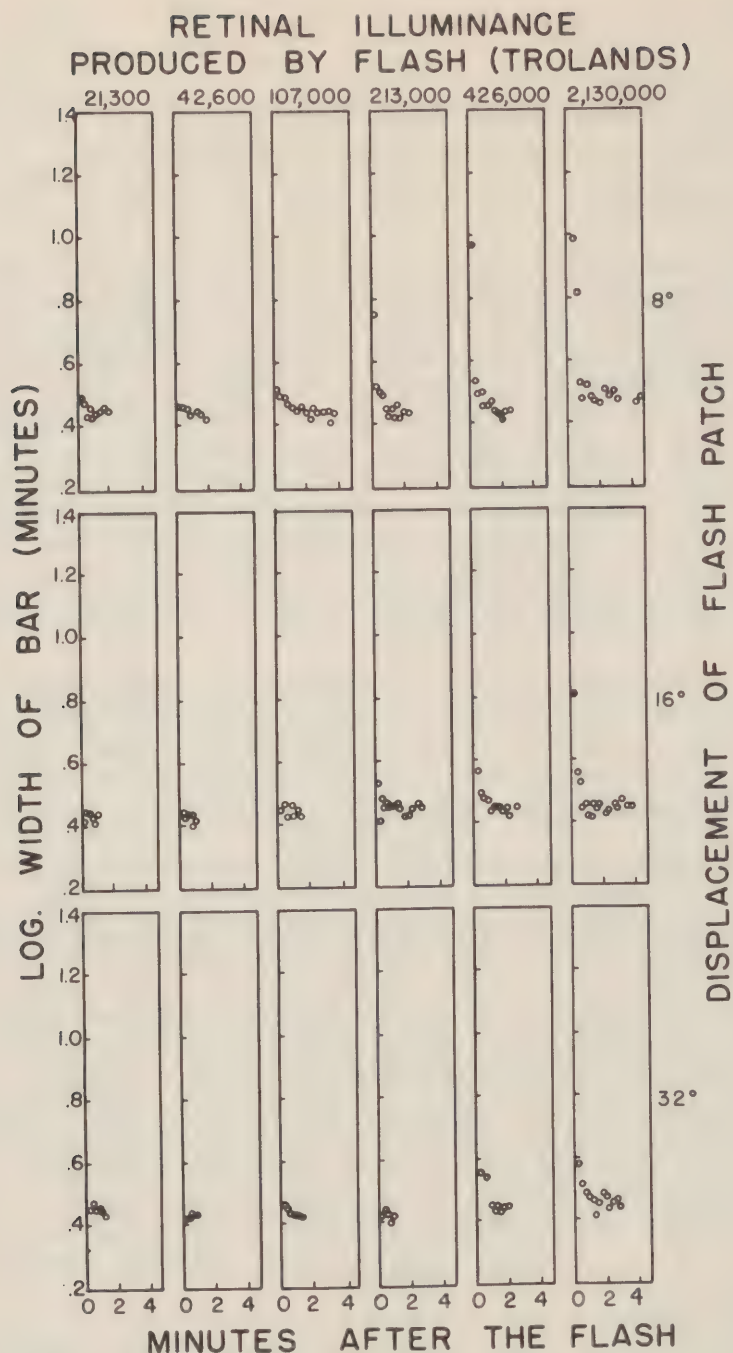


FIG. II

RETURN OF VISUAL ACUITY TO NORMAL FOLLOWING
1 SEC. FLASHES OF DIFFERENT BRIGHTNESS AND
DISPLACED DIFFERENT DISTANCES FROM THE TEST
PATCH.

THE FLASH PATCH WAS EXPOSED 1 SEC. AND
SUBTENDED A VISUAL ANGLE OF 3.5°

DATA FOR M.A.

Both authors of this report participated as subjects in the numerous pilot experiments which were conducted during the perfecting of the apparatus and in the determination of the limits which might be set to the variables. Although the senior author did not participate in the final experiments, it may be claimed that the preliminary observations by him showed no trends which differed from those found for other subjects.

Results

A. The Effect of Varying the Duration and Brightness of the Flash Patch When the Flash Patch is Coextensive with the Test Patch.

The results obtained with flashes of various brightness and various durations for the three subjects are presented in Figs. 9A, B and C. The records for different durations at the same brightness level were obtained in a single experimental session for each subject. Records were obtained for exposures of 1, 10, 100 and 1,000 milliseconds as well as for 3, 30, 300 and 3,000 milliseconds, but these data have not been included in the figures because of the convenience in analyzing the results afforded by having both the brightness variations and duration variations in log unit steps. The graphs arranged in diagonal rows sloping from left to right represent constant exposure in the sense that the product of brightness by time is constant. Without a more detailed analysis of the results the conclusion might be drawn that up to 3 sec reciprocity holds between duration and brightness; that is to say, the total exposure is the thing that determines the degree of impairment of the ability to see with the parafovea and also the time required for this ability to return to normal.

B. The Effect of Repetitive Exposures of the Flash Source.

In order to demonstrate the validity of the principle of reciprocity in the case of intermittent exposure, experiments involving a sequence of thirty flashes at a frequency of ten per second were carried out with two observers. The brightness and duration of the separate flashes were varied but the total exposure, that is the product of brightness by duration by the total number of flashes, was kept constant. The results are shown in Figs. 10A and 10B. It can be concluded from this experiment that the reciprocity principle still holds with intermittent exposures.

C. The Effect of Varying the Distance of a Flash Patch from the Test Patch.

Fig. 11 represents the data obtained from one of the subjects showing the effect of varying the brightness and the amount of displacement of a flash patch from the test patch.

On the assumption that the effect produced by a displaced flash patch results from the stray light which produces a veiling illuminance over that region of the retina on which the image of the test patch falls, one can determine from Fig. 9A the brightness of a flash patch which is applied to the same area of the retina as the test patch that produces the same result as the displaced flash patch. This constitutes a measure of the stray light (or veiling illuminance) produced by the displaced flash patch.

It can be noted in Fig. 11 that the effect produced by a one-second exposure of a flash patch 8° from the test patch and producing a retinal illuminance of 107,000 trolands is approximately the same as for one 16° from the test patch and producing 426,000 trolands or one 32° from the test patch and producing 2,130,000 trolands. Furthermore, as can be observed in Fig. 9A this effect is equivalent to that produced by a one-second exposure of a flash patch superimposed on the test patch and producing a retinal illuminance of 44.1 trolands.

These facts are presented graphically in Fig. 12, which shows the displacement and retinal illuminance of flash patches (3.5° in diameter) that produce a veiling illuminance of 44.1 trolands over the image of the test patch.

Moon and Spencer,^{1,2} on the basis of the data of Holladay³ and Stiles⁴, have recommended the use of the following equation for computing the veiling brightness (B_V) at one part of the field of view produced by a patch of brightness (glare source) in a different part of the field.

$$B_V = k \theta^{-n} E = k \theta^{-n} B_G \omega \cos \psi \quad (7)$$

where k and n are constants and are equal to 10 and 2 respectively. θ is the angle in degrees between the center of the test patch and the center of the flash patch; E is the illumination in the plane of the pupil produced by the glare source; ω is the solid angle in steradians subtended by the glare source, B_G is its brightness, and ψ is the angular deviation of the pupillary axis from the glare source. This equation does not hold for values of θ smaller than 2° .

Since, in the case in hand, the beams of light from both the test patch and the flash patch are restricted and enter the eye without interference from the natural pupil, the term $\cos \psi$ which allows for the obliquity of plane of the natural pupil may be dropped. Furthermore, in computing retinal illumination (I) the term $\cos \psi$ may be ignored in the case of restricted beams so that the equation,

$$I = B A \cos \psi, \quad (8)$$

where A is the area of the natural entrance pupil in sq mm, B the brightness in c/m^2 , and ψ the angular deviation of the pupillary axis from the patch of brightness, reduces to

$$I = B A \quad (9)$$

where A represents the area (sq mm) of the cross section of the entering beam at the center of the entrance pupil.

Expressed in terms of retinal illuminance, Equation (7) becomes

$$I_V = I_F \omega \left(\frac{k}{\theta^n} \right) \quad (10)$$

where I_V is the veiling illuminance produced by stray light covering the image of the test patch, I_F is the retinal illuminance in the image of flash patch, and ω is the solid angle subtended by the flash patch. As applied to the set of data in Fig. 12 the solid angle subtended by the 3.5° flash patch is 0.00298 steradians and the value of I_V is constant at 44.1 trolands and hence, if as assumed by Moon and Spencer that $k = 10$ and $n = 2$, then

$$I_F = \frac{(44.1)}{(10)} \frac{\theta^2}{(.00298)} = 1470 \theta^2. \quad (11)$$

The straight line in Fig. 12 is a plot of this equation.

The agreement with the actual data is not perfect, but is good enough to justify the use of Equation (7) for computing the effect of a displaced flash patch upon the subsequent visibility of a dark object against a night sky background.

In accordance with the basic idea that the effect produced by a displaced flash patch is mediated by stray light in the eye, the effects of two or more separate flash patches

may be considered to be strictly additive, and hence Equation (10) may be used in deriving a general equation for computing the stray light at any given point of the retina produced by any distribution of brightness in the field of view.

$$I_V = k \int_0^{\theta'} \int_{\phi_1}^{\phi_2} f(\theta) B \cos \psi \sin \theta \, d\phi d\theta \quad (12)$$

where $f(\theta) = (57.3\theta)^{-2}$ when θ is expressed in radians and is greater than 0.035 . In this equation I_V is the veiling illuminance at a given point P' on the retina corresponding to a given direction OM in the visual field, B is the brightness in any given direction OP which makes an angle θ with OM and has a meridional displacement ϕ from the zero half-meridian through the axis OM . ψ is the displacement of the pupillary axis from OP . ϕ_1 and ϕ_2 represent the limiting values of ϕ for a given zone θ radians from OM for which the value of ψ is less than $\pi/2$. θ' is the value of θ for the largest zone at one part of which the value of ψ is still not more than $\pi/2$.

Equation 12 cannot be used to determine the contribution which is made by the part of the field centered at P and extending out 2° , because the form of the function $f(\theta)$ is not known for values of θ less than 2° . Further study of this problem needs to be made. In applying this equation to the problem at hand, allowance must be made for the changes in pupil size that occur during and subsequent to the flash.

D. The Effect of Varying the Area of the Displaced Flash Patch.

Holladay, Stiles and others have all recognized the importance of the role played by stray light in evaluating the effect of a patch of brightness in one part of the field of view upon the ability to see in another part of the field, but have not been willing to ignore completely the possibility that there may be some interaction between the different parts of the retina by way of nervous mechanisms. Moon and Spencer have also been cautious on this point but have tentatively accepted the proposition that whatever mechanisms exist behave as if the whole effect were mediated by stray light. It is important, therefore, to demonstrate by whatever methods possible that the phenomena do behave as if mediated by stray light and whatever evidence, be it direct or indirect, that bears upon this point ought to be brought forth to add confidence in the basic principle involved in Equations 7 and 12.

If the effect produced by a displaced flash patch is mediated by stray light, then the effect of varying the area of the patch should be completely akin to varying the brightness of the patch. In order to demonstrate the extent to which this relationship does hold, experiments have been carried out in which the brightness and area of a displaced patch have been varied. The results of this sort of experiment for three subjects are presented in

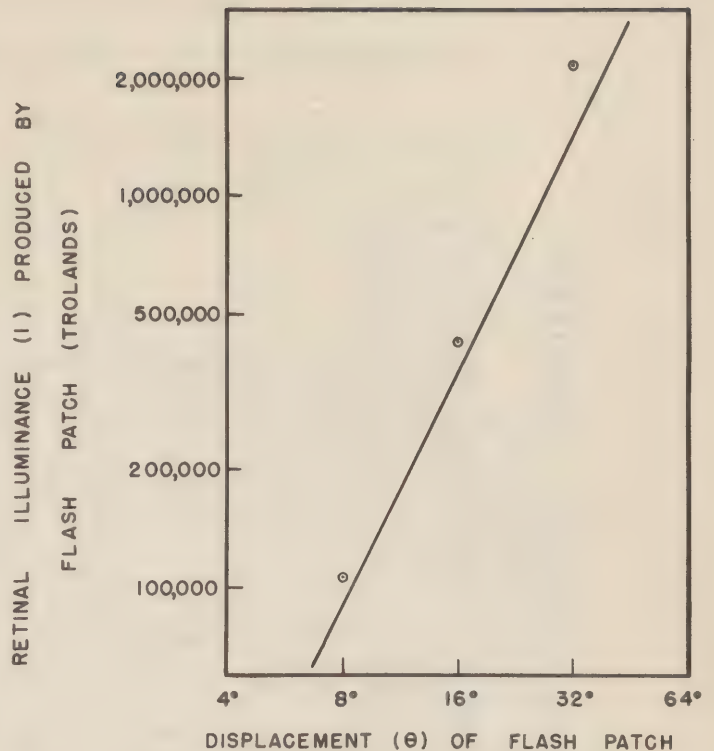


Figure 12. Retinal Illuminance (I_V) Produced by a Flash Patch 3.5° in Diameter and Displaced at Various Angles (θ) From the Center of the Test Patch Required to Produce a Veiling Illuminance of 44.1 Trolands.

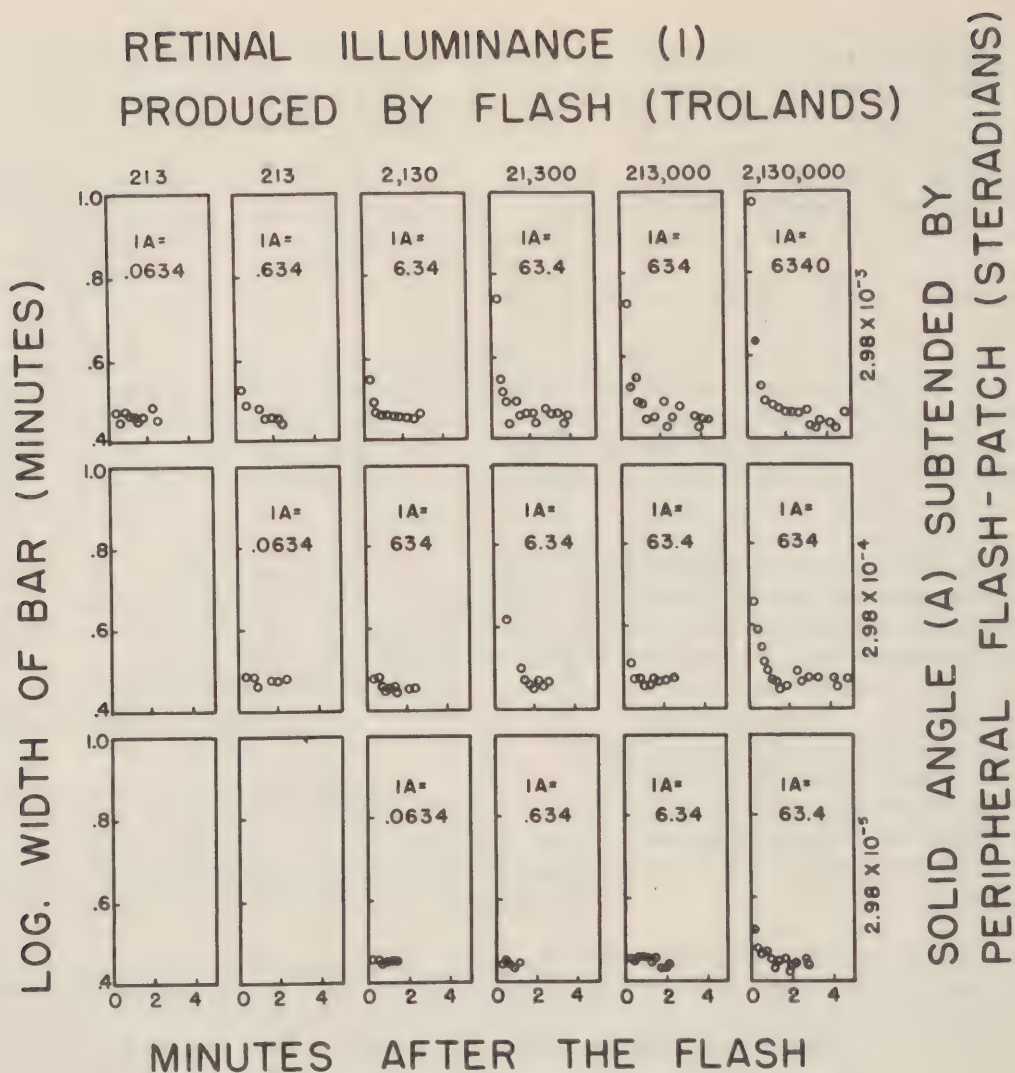
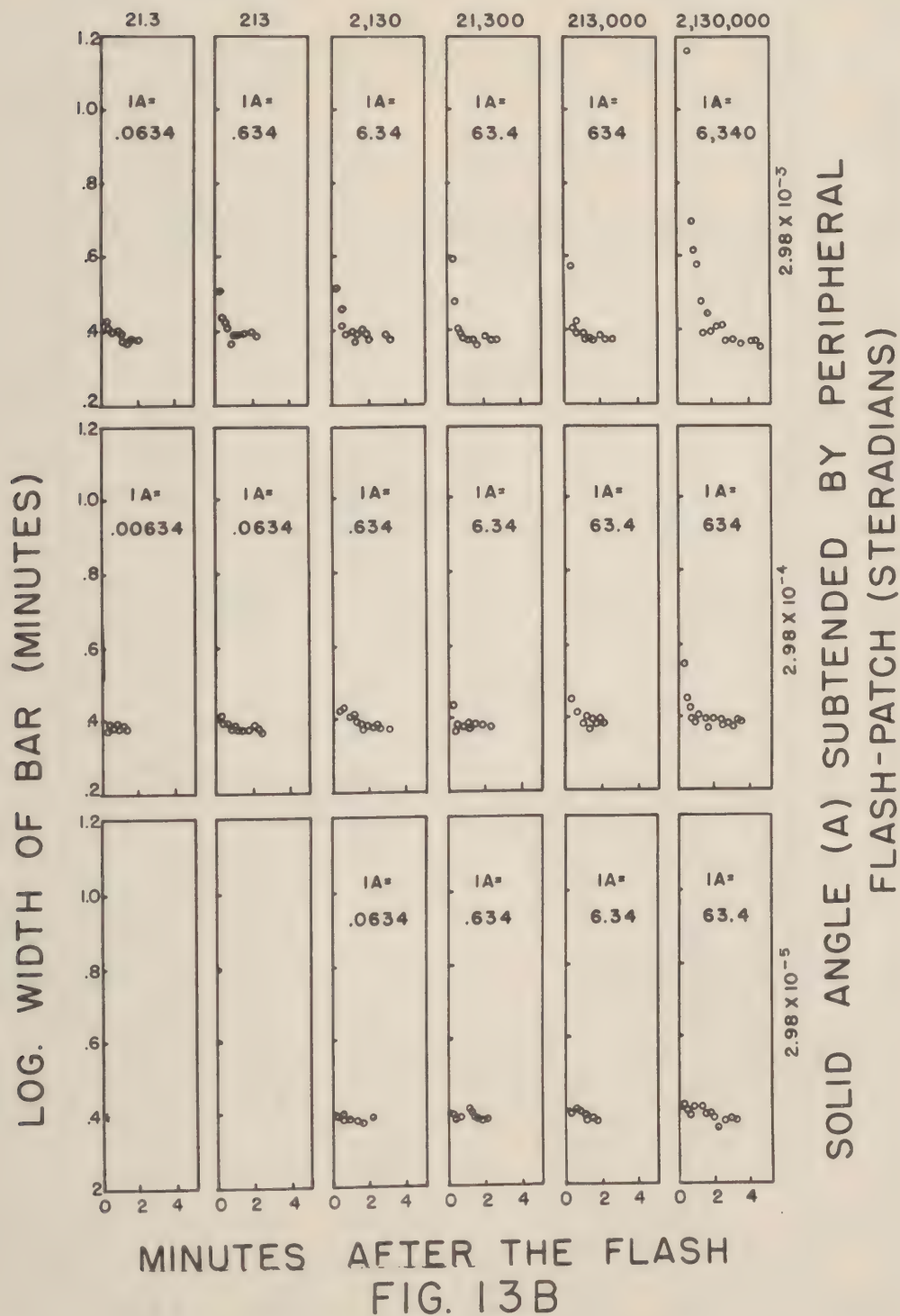


FIG. 13A

RETURN OF VISUAL ACUITY TO NORMAL
FOLLOWING EXPOSURE OF A FLASH PATCH
DISPLACED 8° FROM THE CENTER OF
THE TEST PATCH AND HAVING VARIOUS
ANGULAR SIZES AND BRIGHTNESSES.

DATA FOR P.H. THE DURATION OF
THE EXPOSURE WAS 3 SECONDS.

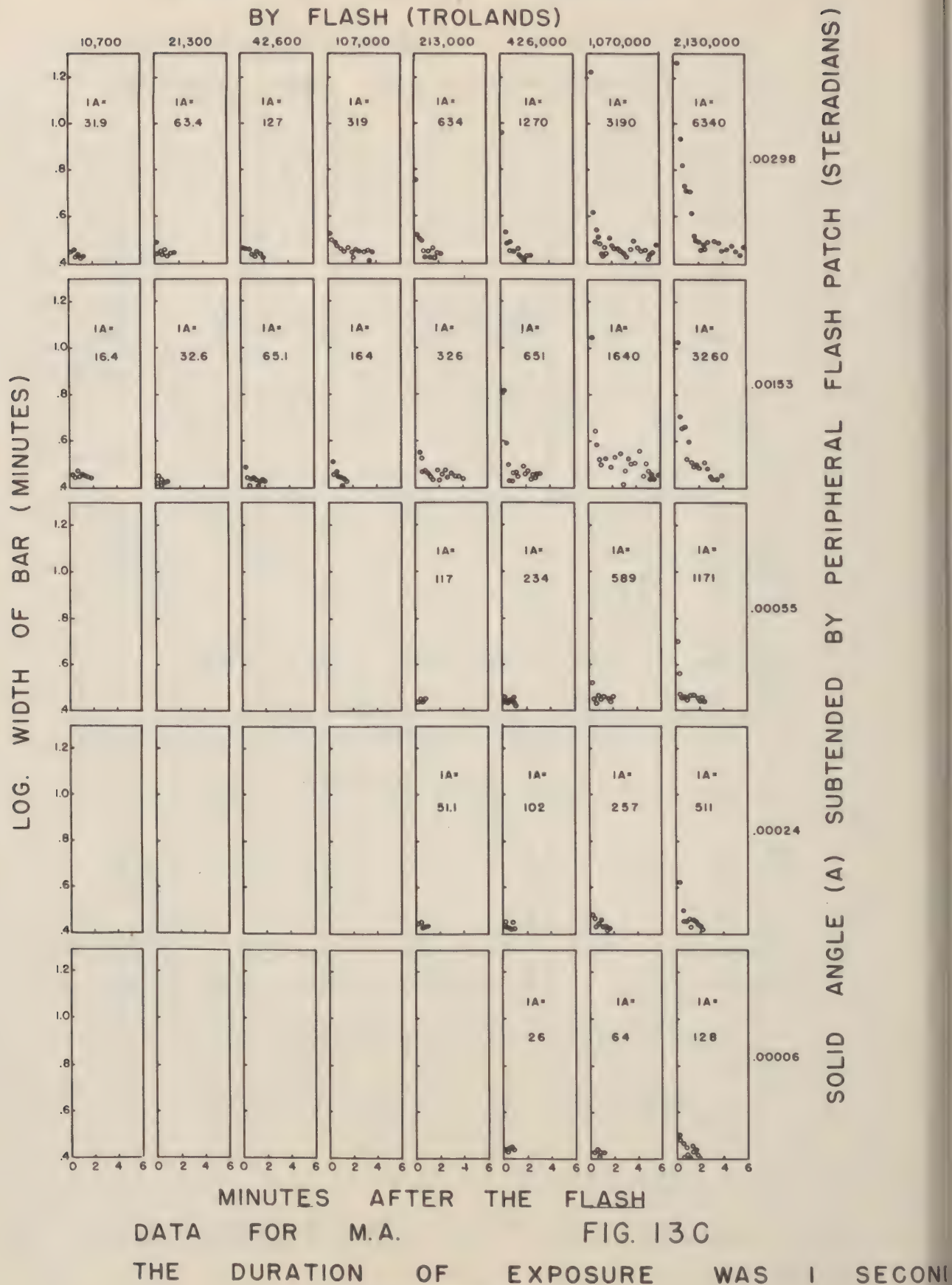
RETINAL ILLUMINANCE (I) PRODUCED BY FLASH (TROLANDS)



DATA FOR L. Z.

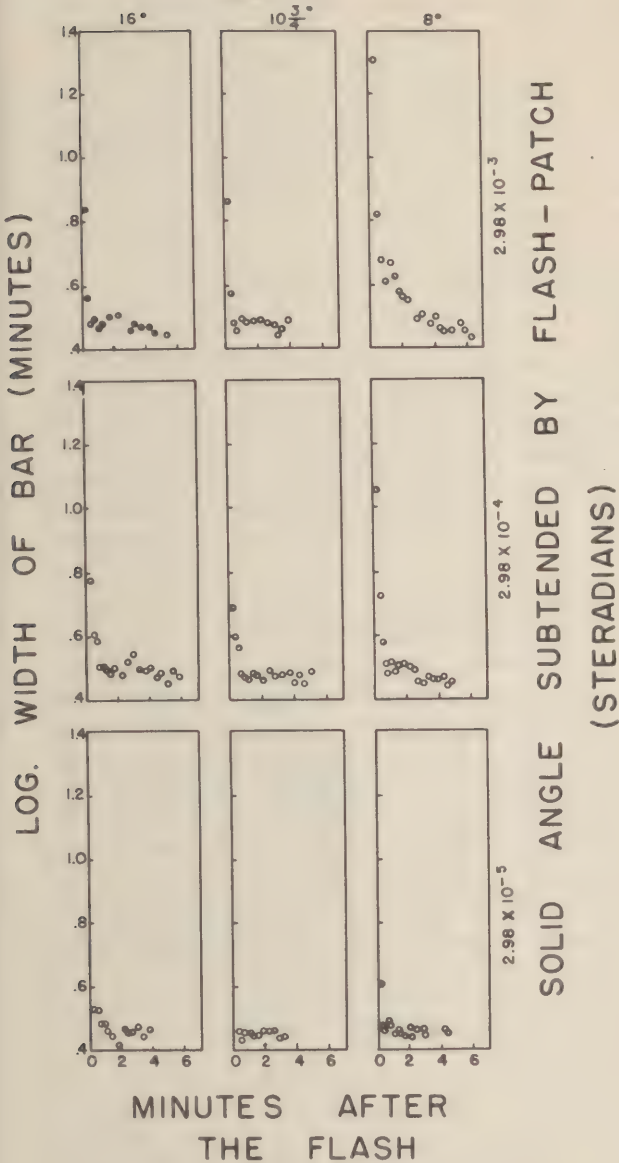
THE DURATION OF EXPOSURE WAS 3 SECONDS.

RETINAL ILLUMINANCE (I) PRODUCED BY FLASH (TROLANDS)



DISPLACEMENT OF
FLASH PATCH

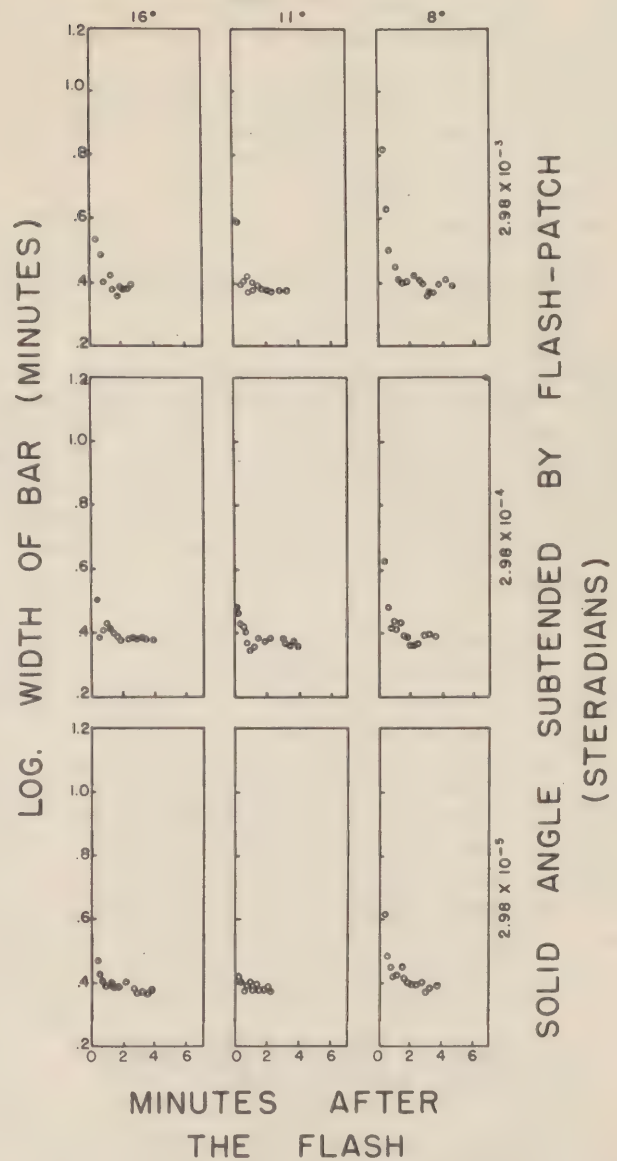
BLIND SPOT



A. DATA FOR P.H.

DISPLACEMENT OF
FLASH PATCH

BLIND SPOT



B. DATA FOR L.Z.

FIG. 14

RETURN OF VISUAL ACUITY TO NORMAL FOLLOWING A 3 SECOND EXPOSURE OF A FLASH PATCH HAVING VARIOUS SIZES, AND APPLIED TO THE BLIND SPOT, AND TO THE RIGHT AND LEFT OF IT.

THE PATCH PRODUCES A RETINAL ILLUMINANCE OF 2,130,000 TROLANDS.

Figs. 13A, 13B, and 13C. In the case of subjects P.H. and L.Z., the area as well as the brightness was varied in log unit steps; consequently, diagonal rows of graphs sloping from left to right represent products of area and brightness which are constant. In the case of subject M.A., different steps were used in varying the area; consequently, the analysis is somewhat more difficult by casual inspection. If anything, the effect of varying the area appears to be somewhat more effective than varying brightness, but the difference is probably not significant and it may be concluded that the effect of a displaced flash patch is mediated by stray light or some equivalent mechanism.

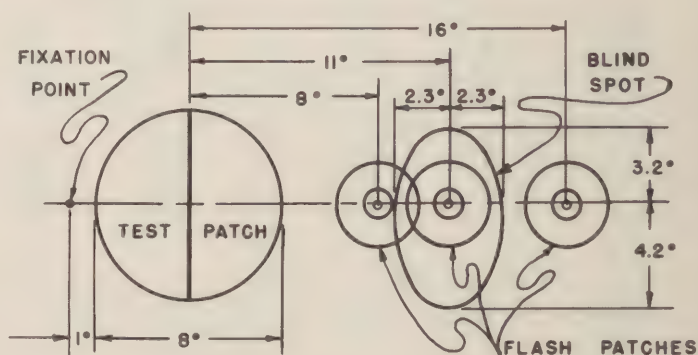
E. The Effect of a Flash Patch which Falls in the Blind Spot.

In Figs. 14A and 14B a comparison is made, in the case of two subjects, of results obtained with flash patches that fall in the blind spot and to the right and left of the blind spot. The flash patch to the left of the blind spot is of course closer to the test patch, and consequently the effect is much more pronounced than in the case of the flash patch on the right. The important thing is that the effect produced by a flash patch falling in the blind spot is intermediate between that produced by a flash patch on either side, at least at the higher brightness levels. This indicates that little is added by having an active retina underneath the image of the flash patch. In other words, in this sort of phenomenon the retina acts purely as a reflector.

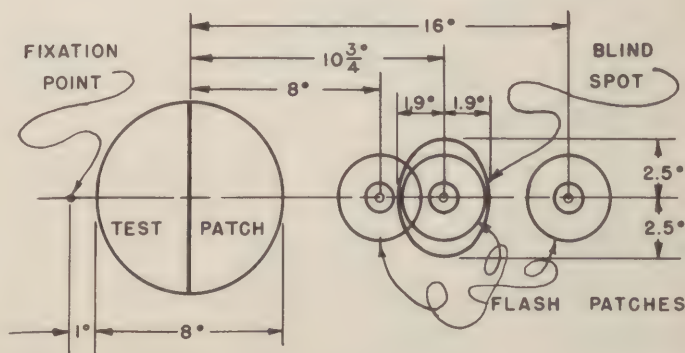
With the heads of the subjects mounted in the instrument, the blind spots were mapped out with the subjects fixing the fixation point and with the targets for mapping the blind spot kept in the plane of the aperture A'_4 . In this way it was possible to demonstrate directly that the displaced flash patch fell within the blind spot when placed 11° from the center of the test patch in the case of P.H. and $10\frac{3}{4}^\circ$ in the case of L.Z. The test patches in relation to the blind spots are shown in Fig. 15.

F. The Effect of Using Flash Patches Larger than the Test Patch.

In general one expects the adaptation of the eye to be a function of the adaptation of photoreceptors within the eye, and consequently if one were to increase the diameter of the flash patch from 8° to 16° or 32° , it would not be expected that this increase in area of the flash patch would affect the adaptation of that region of the retina which receives the image of the test patch except insofar as the total amount of the stray light in the eye would be increased. The total increase in stray light (veiling brightness) at the center of the flash patch resulting from an increase of its diameter from 8° to 16° is equivalent to only 1.3% of its brightness



A. SUBJECT P.H.



B. SUBJECT L.Z.

Figure 15. Location of the 0.35° , 1.11° and 3.5° Flash Patches With Reference to the Blind Spot Which Were Used in Acquiring the Data in Figure 14.

and a further increase in area to 32° would further increase the amount of veiling brightness only 0.4% of the brightness of the flash patch.

As a matter of fact, Wright⁵ has already demonstrated that the adaptation at a given part of the retina produced by direct exposure to a patch of brightness is not measurably affected by the area of the patch.

It appears to be worthwhile, however, for reasons already stated to demonstrate if possible that this principle operates under the conditions of the present series of experiments. Consequently, an experiment was devised in which the area of a flash patch concentric to the test patch was made 6° , 16° and 32° in diameter, respectively.

A special type of exposure device was necessary for this phase of the investigation. This device, illustrated in Fig. 16, is completely separate from the major instrument described above (Fig. 3). It is necessary, therefore, for the subject to bite the biting board of the flash patch exposure device (Fig. 16) in order to have the flash patch exposed to him and then he switches to the biting board of the major instrument in order to observe the test patch.

The head is fixed in space by means of a forehead board and a biting board so that the entrance pupil of the right eye falls at the point E. The lenses L_2 and L_3 constitute a Ramsden type eye piece which focuses an image of the aperture A_1 in the plane of the entrance pupil. P_1 is a beam splitter. Behind the aperture A_1 is a piece of milk glass and a 7.5 watt incandescent bulb, S_1 . The aperture A_1 constitutes an aperture stop. Its image in the plane of the entrance pupil of the eye is 2 mm in diameter. The point of fixation is the aerial image at A_4 of the small pin point aperture A_3 formed by the lens L_1 . This point of fixation is seen at an angular distance of 5° from the center of the aperture A_2 . When the aperture A_2 subtends a visual angle less than 10° , it is necessary to put a second small aperture in the same diaphragm at A_4 in order to permit the image of A_3 to be seen at A_4 . When A_2 subtends a larger visual angle than 10° , the second aperture is unnecessary. Apertures at A_2 subtending visual angles of 8° , 16° and 32° have been used. The duration of exposure was approximately 3 seconds. The source S_1 was turned on and off by a microswitch activated by a revolving cam driven by a constant speed motor.

The procedure in carrying out the experiment was as follows. The forehead rests and biting boards of the two instruments were adjusted so that the entrance pupil of the right eye would fall at the proper points. After 30 minutes of dark adaptation, the subject bit the biting board of the major instrument and fixated the

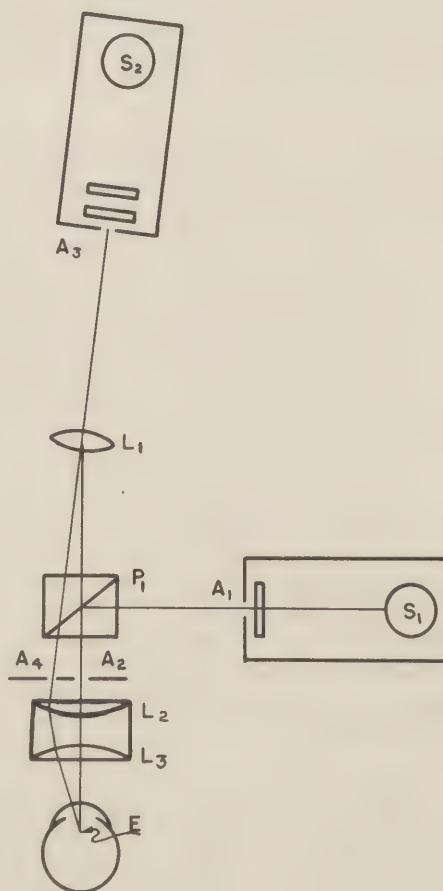


Figure 16. Apparatus for Presenting Large Flash Patches to the Eye.

fixation point steadily. The operator started the recording apparatus, and several determinations and recordings of the threshold width of the bar were made. The subject then bit the biting board of the exposure device and the fixation point steadily while the operator turned on the motor which drove the cam that gives a 3-second exposure. He marked the cessation of the flash on the record. The subject then moved back over to the major instrument for measuring the threshold width of the black bar, bit the biting board, and then fixated the fixation point. The operator, starting with the smallest width of the bar, gradually increased the width of the bar until the bar became visible and then recorded the size of the bar on the recording apparatus. This process was repeated until the threshold width of the bar returned to normal. The experiment was then repeated using a 16° flash patch, and after the effects of this flash patch had worn off, the procedure was repeated using a 32° flash patch.

The results (Fig. 17) indicate that the effect produced is somewhat more pronounced with the larger flash patches. Insofar as the results do differ for flash patches of different size they are in variance with the results previously described. Eye movements and the role played by the border of the positive after-image might account for part of this discrepancy.

G. The Effect of a Flash Patch in the Case of a Test Patch with a Lower Background Brightness than 0.01 Millilambert.

It was intended at the outset of this investigation to explore the effects of bright flashes using a background brightness of 0.0002 millilambert and a 2 mm artificial pupil. However, in exploratory experiments dealing with this problem, it was soon discovered that in the case of three subjects not even the 8° test patch could be differentiated from its dark background at this low level of brightness. The question remained, however, as to what is the lowest level of brightness at which visual acuity measurements can be made, and whether it takes any longer to recover from a flash of light at this lowest level as compared with a background of brightness of 0.01 millilambert. In order to study this phase of the problem and in order to determine the lowest level at which visual acuity measurements might be made, the following experiments were performed.

Subject L.Z. was dark adapted for 30 minutes and then exposed to a flash patch superimposed upon the test patch for one second. The brightness of this flash patch was such as to produce a retinal illumination of 14,700 trolands. Following the flash, the recovery of visual acuity was measured in the normal manner using a background brightness producing 0.107 troland. The only deviation from the usual

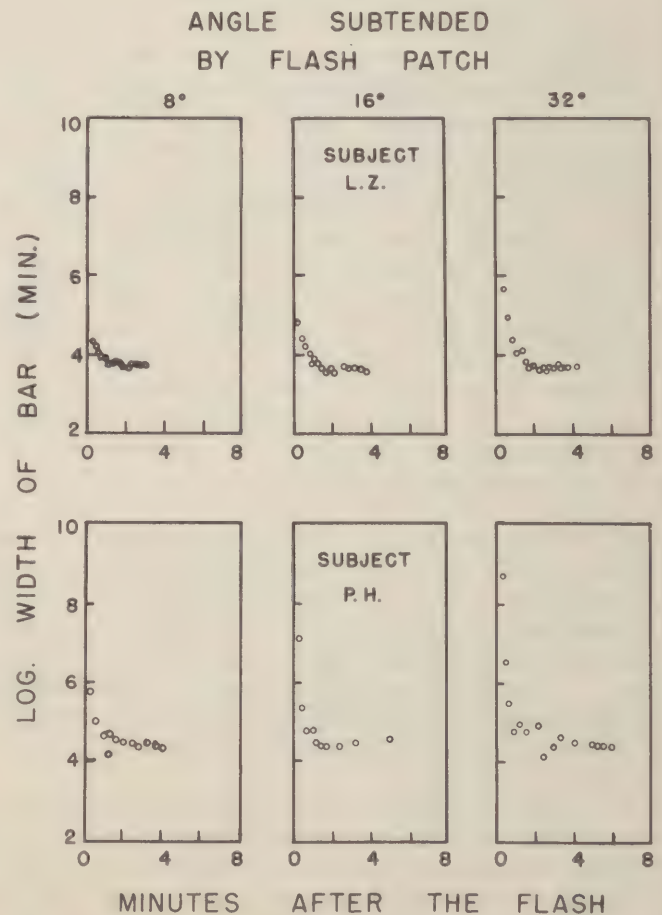


Figure 17. Return of Visual Acuity to Normal Following a Three-Second Exposure to a Flash Patch Producing 101.5 Trolands of Retinal Illuminance Placed Concentric to the Test Patch and Having Various Angular Sizes.

procedure was that a one-mm vertical line was used which provided a range of visual angles from 4 to 64 minutes. When it appeared certain that the visual acuity had reached a constant level, the brightness of the test field was dropped by means of a variac to a brightness level producing 0.049 troland and a series of visual acuity measurements were made to trace the process of dark adaptation to this lower level. After the visual acuity measurements had leveled off at this brightness level, the brightness was dropped again to a level producing 0.024 troland and another series of visual acuity measurements was made. An attempt was then made to repeat the process at brightness levels producing 0.011 troland and 0.005 troland.

At this last level not only was the bar invisible but also its background could not be differentiated from the surround. Following this the brightness was raised back again through the same steps to the level of 0.107 troland and at each level a series of threshold widths was determined. The data for this experiment are plotted in Fig. 18A.

The same sort of experiment was carried out for subject P.H., except that following the 30 minutes of dark adaptation, the bright flash was omitted and the subject proceeded immediately to make a series of visual acuity measurements at a retinal illuminance level

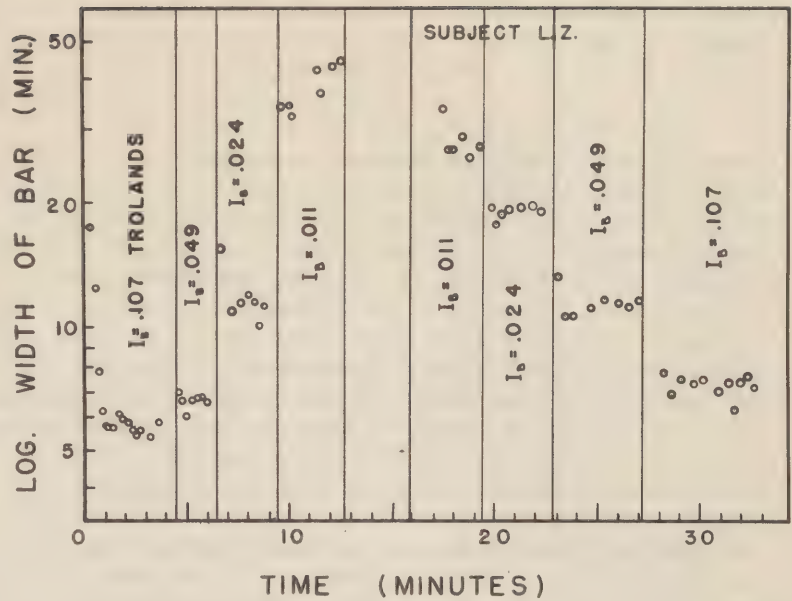


Figure 18A. Visual Acuity Measurements at Various Brightness Levels Made in the Sequence Indicated. Zero on the Time Scale Indicates the End of a One-second Flash Which Was Coextensive with the Test Patch and which Produced a Retinal Illuminance of 14,700 Trolands.

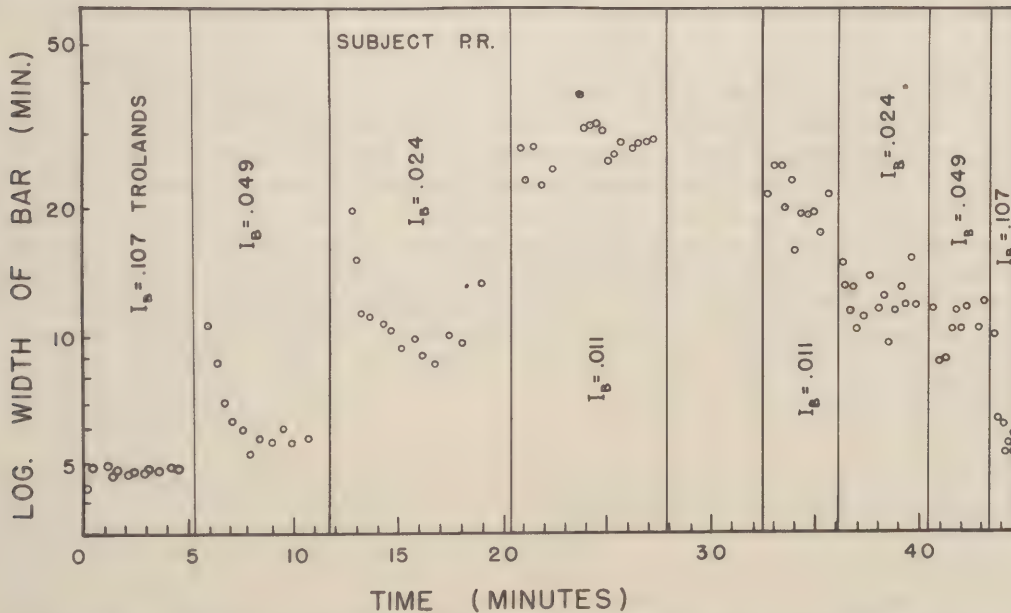


Figure 18B. Visual Acuity Measurements of Various Brightness Levels Made in the Sequence Indicated. This Series of Measurements was Preceded by 30 Minutes of Dark Adaptation.

of 0.01 troland. The remainder of the experiment was carried out in the same way as for the subject L.S. The data are shown in Fig. 18B.

The data for P.H. indicate that when the level of the retinal illuminance is dropped to a lower level, a short period of time is required to dark adapt to this lower level. Only one instance of this sort of thing is found in L.Z.'s record; namely, when the level of retinal illuminance was dropped from 0.049 to 0.024 troland. The data in the second half of the experiment for each subject were analyzed by averaging at each retinal illuminance level the threshold widths of the bar and then plotting these average widths as indicated in Fig. 19. These data explain why visual acuity measurements cannot be made at lower levels of retinal illuminance. At a level of 0.005 troland the width of the bar can be extended indefinitely without reaching a threshold value. These data are in agreement with the data of Hecht and Mintz⁷, who also used a dark bar on a uniform background for measuring visual acuity at low levels of retinal illuminance.

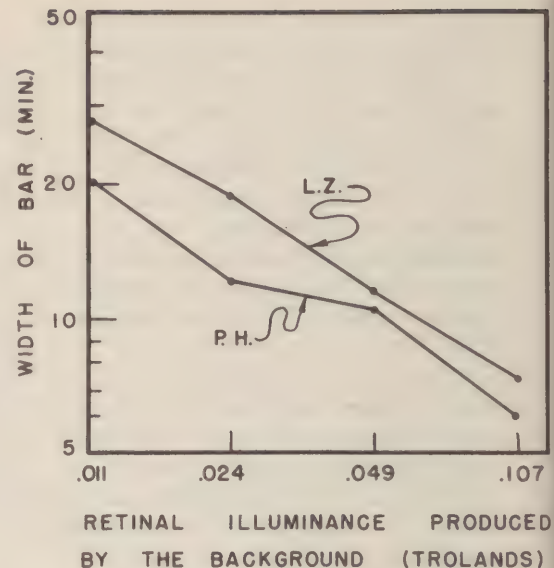


Figure 19. The Effect of Brightness Level Upon the Threshold Width of the Bar.

THEORETICAL CONSIDERATIONS

A. The Advantages and Limitations of the Visual Acuity Method of Measuring Dark Adaptation.

One feature of this method is that in tracing the course of dark adaptation, the retina is constantly exposed to the level of retinal illuminance toward which it is becoming adapted.

When the flash is very bright and the duration long, it is not possible to trace the course of dark adaptation during the period immediately following the flash. There is an upper limit beyond which increasing the width of the bar does not improve its visibility, and this is the thing which limits fundamentally the extent to which the course of dark adaptation can be traced by the visual acuity method during the early phases of the process.

In the case of foveal vision, where the number of ganglion cells in the retina is sufficient to provide each photoreceptor with its own private pathway up the optic nerve, the blurredness of the retinal image is the primary factor which determines the relationship between the width of a bar and its visibility. However, in the case of peripheral vision where the number of ganglion cells is much smaller than the number of photoreceptors, a large number of photoreceptors must converge upon a single ganglion cell and area summation can be expected to be a factor.

The data in Figs. 18A and Fig. 18B and in Fig. 19 indicate that increasing the width of the bar up to 40 minutes of arc improves its visibility.

It would have been possible to continue this experiment by using bar widths exceeding those used and varying the brightness of the background to measure the threshold. In this way one could trace the experiment to bar widths which yield constant thresholds.

At any given level of background brightness this problem could be studied by varying both the contrast and the size of the bar.

B. The Form of the Curve to be Used to Represent the Data.

No attempt has been made at the theoretical level to determine the type of curve which ought to be used to fit the data showing the recovery from a flash. It involves not only the relationship between the photochemical process in the rods and the discharge of impulses, but also the mechanisms of interaction between the retino-cortical pathways which determines whether a border is seen or simply washed out. It is hoped that it will be possible later to undertake this sort of analysis of the data.

The problem is made somewhat easy by the fact that the measurements are all made with a background brightness producing a retinal illuminance of 0.01 troland or less, and at these levels only rods are involved.⁶

C. The Use of a Long Narrow Bar for Measuring Visual Acuity.

Attention should be drawn to the advantage of using a long dark bar on a uniform field. In the first place, it makes it easy to assess the role played by spatial summation between the retino-cortical pathways. In the second place, it is easy to relate the visibility of such a test object to the visibility of a straight border separating bright and dark areas. As a matter of fact, as the width of the bar is increased, the problem eventually becomes transformed into one of the visibility of a border separating dark and light areas. In the third place, the mechanism of interaction between retino-cortical pathways which is involved in determining the visibility of the border is much easier to visualize and analyze when a straight border is used as compared to a curved one such as is encountered with a circular test object.

D. The Role Played by Eye Movements.

Eye movements undoubtedly impair the precision of the data in the kind of experiments described above. Under the conditions of these experiments it is very difficult to maintain steady fixation, and this might cause considerable variation from reading to reading.

E. The Psychophysical Method.

The method employed for measuring the threshold, which involves bringing the size of the target from the sub-threshold width to the threshold of visibility and which depends upon the subject's ability to determine when the bar is at the threshold of visibility, leaves a good deal to be desired. A more effective technique can no doubt be devised, but would require more elaborate apparatus and much more time both in acquiring the data and in analyzing it. It was not felt that extreme precision was the major objective, and it is believed that the data acquired do provide satisfactory answers to the problems which were to be solved.

F. Positive After Images.

A complete theoretical interpretation of the data in this report must involve consideration of the positive after image produced by the flash as well as the depletion of the available photosensitive substance in the photoreceptors.

SUMMARY AND CONCLUSIONS

This investigation has succeeded in demonstrating the operation of three basic principles which can be used in predicting the effect of a flash upon the subsequent ability of an eye to see dark objects against a night sky background.

- (1) The adaptation of any given part of the retina can be regarded as being independent of adaptation processes in other parts of the retina.
- (2) Reciprocity between time and intensity can be assumed to hold at least over a three-second interval.
- (3) The effect of a flash displaced from that part of the retina which is used in viewing an object can be accounted for in terms of stray light. The amount of stray light falling at any given part of the retina can be computed from the Stiles-Holladay equation. (Equations 7 and 12).

It is true that the constants and perhaps the form of Equation (7) need to be further verified in order to give more confidence in the use of this equation for engineering purposes. It is already known that the form of this equation will have to be modified for small values of θ . It is believed, however, that a more direct method than the one used here can be used for determining these constants and the best form of the equation, since this method simply demonstrates the operation of the basic principles at low levels of illuminance. Therefore, the repetition of these particular experiments with a larger number of subjects hardly appears to be in order.

The most basic set of data needed for engineering purposes for the problem at hand is the set of data illustrated in Figs. 9A, 9B and 9C, which show the effects of flashes of different brightness and duration.

Since it is shown in these figures that a reciprocity exists between duration and brightness, a single set of curves such as the top row of curves in each figure representing effects for various values of IT would suffice. It would undoubtedly prove of considerable value to have a set of curves which fit the data and which can be expressed in terms of equations. Such a reduction of the data to a set of equations has not yet been attempted. For engineering purposes it might appear sufficient at first sight to select curves which fit the data without reference to the theoretical significance. The limitation to such a procedure is that curves fitted in this way cannot be extrapolated very far beyond the actual conditions of the experiments. Curves which express basic principles give more freedom in this direction.

The data in Figs. 9A, and C apply to a background of 0.0107 troland. Sets of curves for various values of IT and background brightness should be available in order to make calculations for any level of sky brightness.

The lowest level of background brightness at which visual acuity measurements can be made is one which produces approximately 0.01 troland of retinal illuminance.

In applying data obtained with dark bars on a uniform background to practical situations, it must be kept in mind that the visual acuity measured by this type of target is better than that obtained by almost any other type of target, for example, by a pair of bars or a Landolt C or a dot, or a letter. Consequently, allowance for this difference must be made when using data obtained with a single narrow bar in attempting to predict the effect of a flash of light upon the visibility of targets of a more complex configuration. At low levels of retinal illuminance, one is concerned primarily with the detection of large objects, and for this purpose the data obtained with long narrow bars apply directly.

In this study we have dealt with large patches of brightness uniformly distributed in

the field of view, or with displaced patches which produce an indirect effect through stray light which is uniformly distributed over the retina. If the region of the retina used for viewing an object is previously exposed to a finely articulated pattern involving sharp high contrast borders, this chopped up pattern of adaptation introduces a complication which has not been considered in this study.

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Discussion:

Dr. Knoll suggested that, if the effect of a bright flash of light is entirely due to stray light within the eye, the effect should be greater when the source of stray light falls upon the blind spot than when it falls upon adjacent areas having lower reflection factors. Dr. Knoll asked if there was any indication of such an effect.

Dr. Fry replied that such an effect did not always occur, but there was sometimes an indication in this direction.

Mr. Breckenridge asked if the results of Dr. Fry's study would be applicable to blind flying in on an approach light system, where the pilot would be confronted by bright flashes and would be trying to see a light in surroundings already moderately bright.

Dr. Fry stated that, although the research had a particular source of immediate application, it had been conducted in such a way that application to other problems could be easily made. Dr. Fry stated that two general principles seemed to be operative. First, it appears that adaptation of any portion of the retina is independent of other portions of the retina. Second, the effect of the distribution of light in the visual field can be explained by the action of stray light alone. There is, however, one area where information is lacking. This concerns the effect of glare sources nearer than 2° to the test target. If the effect of glare sources this near test targets could be established, then it would be possible to build a device to evaluate the adaptation loss to be expected from any distribution of light in the visual field. Such a device might take the form of a photoelectric recorder with a responsivity to light coming from various portions of the visual field corresponding to the losses found to occur with the human eye.

CDR. Farnsworth wished confirmation on his understanding that the apparatus in Dr. Fry's experiment prevented light from falling on the iris and other exterior membranes.

- Dr. Fry assured him that this was correct. A beam of light 2 mm. in diameter passed through the pupil. There was no chance of stray light coming in through the outer tunics.
- Dr. Allen stated that it was his understanding that Dr. Fry used the Stiles-Holladay equation for computing stray light within the eye. This equation involves a coefficient which depends in value upon the reflection factor of the retina of individual subjects. Dr. Allen asked Dr. Fry if there were any differences in this reflection factor between blonds and brunets.
- Dr. Fry replied that differences in reflection factor had not been computed, since the present data were inadequate for establishing this point. Dr. Fry stated that he would expect the reflection factor to vary from individual to individual but that he was not aware of any general data relevant to this question. Differences between individuals with respect to the reflection factor should show up as differences in the constant in the Stiles-Holladay equation. However, Dr. Fry cautioned that differences in the scattering coefficient of the ocular media would also influence the value of the constant.

THE EFFECTS OF TWO INSTRUMENT LIGHTING SYSTEMS ON DARK ADAPTATION *

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I. INTRODUCTION

The problem of lighting of aircraft cockpits for night flying presents a somewhat paradoxical situation. On the one hand, low illumination levels are required so that vision outside the aircraft is impaired as little as possible; on the other, higher illumination levels are necessary to allow the pilot to read his instruments quickly and accurately. A constant effort to improve visual conditions in the cockpit has brought about many modifications of instruments and the methods of lighting them. The preservation of dark adaptation has been one of the main considerations governing these modifications and has been stressed whenever discussions of night lighting have taken place. In the development of instrument lighting systems it has been the goal of the lighting engineer to create a system that will have as little effect as possible on the level to which the pilots' eyes have been dark adapted. Dark adaptation is a chemical process which takes place in the retina of the eye, allowing the individual gradually to see more and more of his surroundings as time expires after he has gone from a well-lighted environment into a darker one. The process is, for all practical purposes, completed after a period of 35 minutes in total darkness. When the eye has been dark adapted, i.e. in total darkness for 35 minutes, extremely dim objects can be seen. As the retina is subjected to illumination higher in intensity than this faintest possible stimulus, the reverse chemical process is started and retinal sensitivity decreases to a point where the original stimulus can no longer be seen. When the eye becomes adapted to the higher illumination, this level, which is between the totally dark adapted state and the completely light adapted one, is referred to as the adaptation level. There are, of course, numerous possible adaptation levels.

There has been no attempt as yet to determine the decrease in retinal sensitivity brought about by exposure of the dark adapted eye to the various levels of night-sky brightness; nor has it been adequately determined what happens to the dark adaptation level of the pilots' eyes when exposed to the various available instrument lighting systems. It is possible that under many conditions of night-sky brightness the adaptation thresholds resulting from exposure to the light from outside the cockpit will be above the level brought about by the lighting systems alone. Accurate data on these two subjects will provide a basis for judging the effectiveness of our present lighting systems.

To date, the evaluation of lighting conditions in aircraft cockpits has been more or less a subjective one, wherein surveys or discussions have been conducted to find out how pilots react to a specific system, i.e. like or dislike it. On the other hand theoretical considerations have, and justly so, played a very important part in lighting systems development. The present acceptance of red light as the primary method of illumination was supported by studies (2,5) which show that dark adaptation is affected less by light from the red end of the visible spectrum than that of other wave lengths. To repeat, however, the magnitude of

* This report also appears as WADC Technical Report 52-263, dated December 1952.

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the loss of dark adaptation under actual night flying conditions has not been determined.

II. PURPOSE OF THE STUDY

The purpose of this study was (1) to determine the effect of two different instrument lighting systems on adaptation levels, (2) to determine the effect of night sky brightness plus the lighting systems on the adaptation level of the eyes of the pilot, and (3) to compare the two resulting sets of data to determine the effectiveness of these lighting systems.

III. APPARATUS

Instrument Lighting System:

The two lighting systems under consideration in this study, red flood, and indirect red, are both installed in the Aero Medical Laboratory's Airborne Psychology Laboratory, a specially equipped C-47 aircraft. The red flood lighting system is the standard one installed in service aircraft and consists of fixtures installed so as to flood the instrument panel with red light. The indirect red system is composed of small red lamps strategically located around the instruments and covered by an overlay panel. This installation differs from the individual lighting shields now in service use. The illumination of the instruments, however, is comparable. This indirect red installation provides excellent individual instrument illumination with light falling only on the face and pointers of the instruments.

Portable Adaptometer:

The instrument used to determine the decrease in retinal sensitivity, a portable adaptometer, was designed and constructed by Major L. R. Wilcox to be used under actual flight conditions (Figure 1). It was installed above the glare shield in front of the co-pilot's position in the C-47. It incorporates a wedge filter of known density to reduce the brightness of a constant light source. This variable light is projected, within the instrument, onto a milkglass test field in the front surface of the adaptometer. The brightness of the test field is varied by rotating a knob mounted to the left of the test field. This knob controls the position of the wedge in the beam of light between the light source and the test field. The position of the wedge is transmitted through a system of gears to a calibrated dial on the top surface of the instrument in order that the wedge position can be determined.

A red fixation point of adjustable intensity is located to the right of the test field. It is so positioned that when viewed from a distance of 18 inches the angle between the fixation point and the center of the test field subtended at the eye of the observer is seven degrees.

Seven neutral density filters are included with the adaptometer. These may be placed, one at a time, in the beam of light cast on the test field. A range in brightness of the test field from 3.4126 to 7.4103 log micro-micro lamberts is thus provided.

The light source, a "grain of wheat" bulb, powered by three flash light batteries, is set at a constant intensity by aligning the pointer of a milli-amp-meter to a reference line on the face of the meter. The pointer's position is controlled by a rheostat.

The calibration of the adaptometer was made with a Macbeth Illuminometer by measuring the brightness of the test field at relatively high levels. The lower brightness range was computed from the known values of the neutral density filters incorporated. This method of calibration was necessary because of the extreme difficulty encountered in making precise photometric measurements at low scotopic levels. Threshold measurements made first with the portable adaptometer and then immediately with a standard Hecht Schlaer adaptometer

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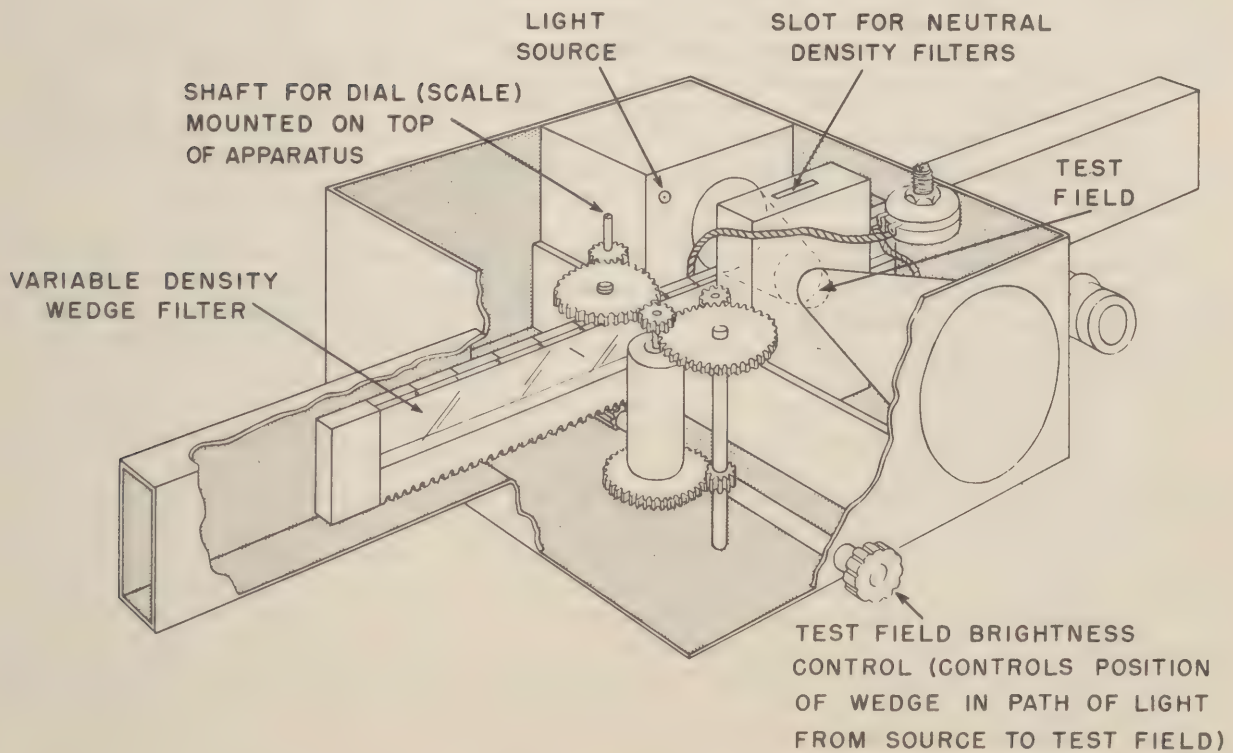
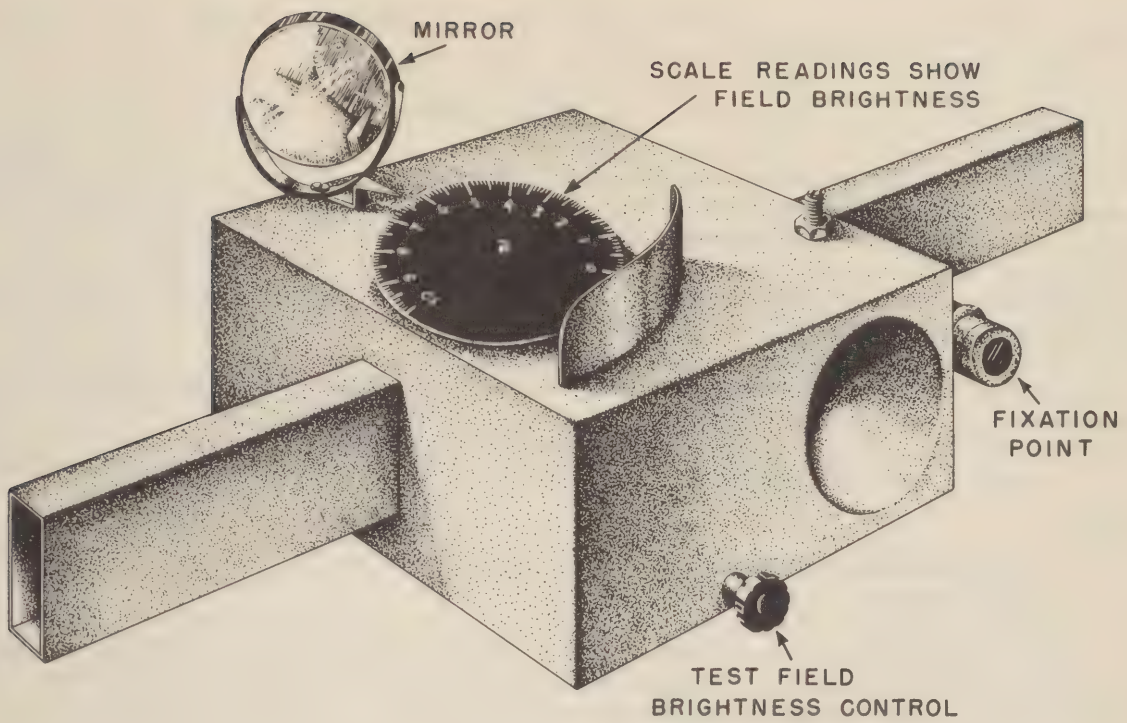


Figure 1.

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validated the calibration of the entire range of the portable instrument.

IV. PROCEDURE

To perform a reliable evaluation of the two lighting systems, it was necessary first to determine which levels of illumination would be used for threshold measurements, and second, to equate these illumination levels for each of the two systems. In an earlier study (3) using the Airborne Psychology Laboratory, 12 subjects, all rated pilots, were required to select three different levels of illumination for each of the two lighting systems. By manual control of the light intensity they selected:

1. The minimum illumination level--the lowest level consistent with safe flight, for use under night flying conditions.
2. The normal illumination level--that which they considered normal for typical night flight.
3. The maximum illumination level--the illumination they would use under night instrument flying conditions.

These three levels were found for both the red flood and the indirect red lighting systems. In the present study, dark adaptation thresholds were measured at each of the three illumination levels for both of the lighting systems.

In order to find the decrement in dark adaptation brought about by: (1) the instrument lighting systems alone, and (2) by the instrument lighting systems and the various conditions of night sky brightness combined, it was necessary to create two different situations. The first was done by excluding completely any outside light from the cockpit. The windshield, windows, astrodome, and all other sources of outside light were covered with many layers of black paper. The aircraft was in a hangar for this phase of the study. In the second situation threshold measurements were made during flight at night, where night-sky brightnesses and the light from the lighting systems both affected dark adaptation. This part of the study was called the flight phase.

The procedure for obtaining threshold measurements in each of the phases was the same. The pilot subjects were first dark adapted for thirty-five minutes in total darkness. Thresholds were then determined before they were exposed to any light. The next step was to light adapt the subjects and take threshold measurements for each of the various levels of illumination listed below:

1. Minimum illumination--indirect red lighting.
2. Minimum illumination--red flood lighting.
3. Normal illumination--indirect red lighting.
4. Normal illumination--red flood lighting.
5. Maximum illumination--indirect red lighting.
6. Maximum illumination--red flood lighting.

The subjects were light adapted to each level of illumination for a period of time long enough to produce stable thresholds by scanning the instrument panel as they would in flight

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for the hangar phase and by actually flying the aircraft in the flight phase. Ten threshold measurements were made. The average of these ten was considered the threshold for a particular illumination level. On completion of these measurements each subject was dark adapted for a short period of time, and his thresholds were checked until the original resting thresholds were reached. Then the subject was light adapted to the next illumination level. The flight phases for all subjects were approximately the same duration and were flown at the same altitude. In addition, the same routes were flown in each case with departure times also approximately the same.

The threshold determination was made by the subject. He fixated on the red fixation point and decreased the brightness of the test field (by rotating the knob) until the test field was no longer visible. This method will be recognized as the method of average error and was selected because of its simplicity and because of the nature of the data being collected. The subject was instructed to make "first choice" determinations since delay--selection and manipulation of the sensitivity of the test field--would produce variations in thresholds as a function of time.

V. RESULTS

The intensity values selected for the red flood and indirect red lighting systems were taken from a previous study as representative of those values used by pilots in actual night flight. These are given in Tables I and II. The dark adaptation thresholds obtained immediately prior to the hangar phase and used thereafter as the base levels for each subject are given in Table III. Figures 2, 3, 4, and 5 * give comparison data of indirect red and red flood between the hangar and flight phases for each subject. Figure 6 represents a combination of the data for all subjects given individually in Figures 2, 3, 4 and 5. A quadruple analysis of variance was done and the results obtained given in Table IV. Table V gives the night-sky brightness of the four nights the subjects were flown.

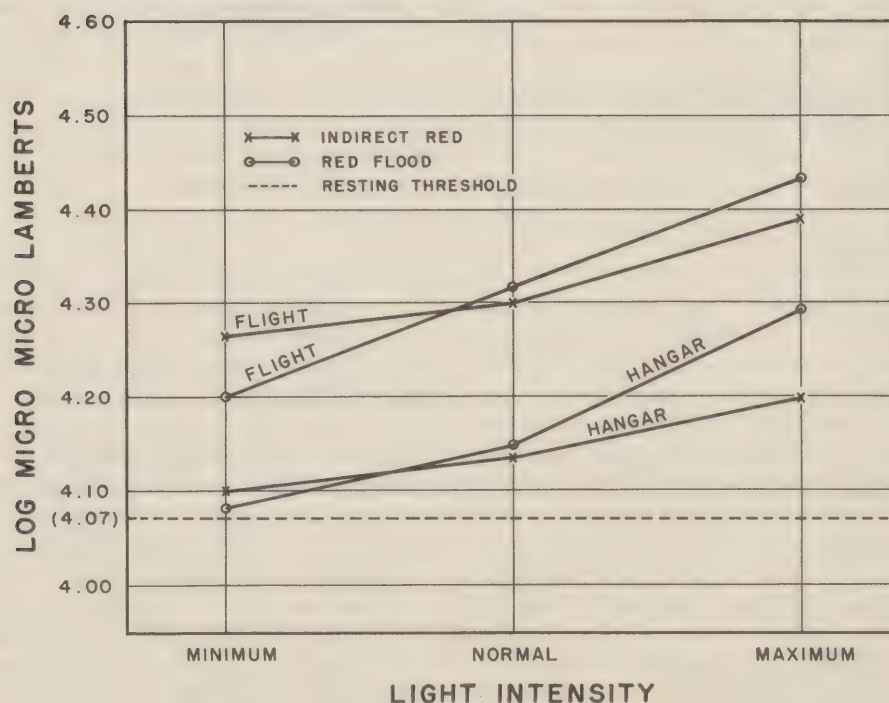
Discussion of Results:

As shown in Table IV the between-group variance attributable to light intensity, phase (hangar vs. flight) and individuals is significant at greater than the .01 level of confidence. Kind of light, i.e., red-flood vs. indirect-red, had no significant effect on dark adaptation thresholds. Light intensity effects were to be expected, of course. Individual differences, while significant, show an interesting parallel. Figures 2, 3, 4 and 5 which give the individual thresholds for the conditions of the study indicate that three of the subjects were relatively alike in terms of thresholds obtained before and during the experiment. However, subject #4, although responding similarly to the other three, started with a markedly higher threshold and remained so throughout the experiment. Thus, it appears quite evident that the individual variance is due almost entirely to subject #4. The phase variance, i.e., flight vs. hangar as indicated above, is significant at better than the .01 level of confidence. It will be noted from Figures 2, 3, 4 and 5 that the thresholds for the flight conditions are consistently higher than for the hangar phase. Thus it would appear that the conditions of night-sky brightness and transient ground lights had an effect on the dark adaptation thresholds of the subjects. Further, it appears that the flight conditions had a greater effect on the dark adaptation thresholds than did either the red flood or indirect-red lighting systems themselves. If this is true, and the data reported here tend to support this view, then it can be stated that the present state of development of lighting systems for aircraft is satisfactory insofar as dark adaptation is concerned.

* Figures 2, 3, 4 and 5 are not reproduced in this report.

(FROM ORIGINAL DATA)

SUBJECT	INDIRECT RED FLIGHT			INDIRECT RED HANGAR			RED FLOOD FLIGHT			RED FLOOD HANGAR		
	MIN	NOR	MAX	MIN	NOR	MAX	MIN	NOR	MAX	MIN	NOR	MAX
1	4.35	4.35	4.32	4.05	4.14	4.18	4.08	4.16	4.26	3.97	4.01	4.08
2	4.10	4.05	4.23	4.00	3.98	4.12	4.00	4.14	4.26	4.00	4.10	4.26
3	4.02	4.13	4.24	4.07	4.00	4.08	4.09	4.18	4.32	4.00	4.04	4.17
4	4.59	4.68	4.77	4.27	4.40	4.58	4.61	4.77	4.87	4.37	4.45	4.64
TOTAL	17.06	17.21	17.56	16.39	16.52	16.96	16.78	17.25	17.71	16.34	16.60	17.15
MEAN	4.26	4.30	4.39	4.10	4.13	4.24	4.20	4.31	4.43	4.08	4.15	4.29



MEAN DARK ADAPTATION RESTING THRESHOLD AND MEAN THRESHOLDS AFTER EXPOSURE TO THREE LIGHT INTENSITIES DURING FLIGHT AND HANGAR PHASES FOR ALL SUBJECTS.

Figure 6.

TABLE I

MINIMUM	.0125
NORMAL	.034
MAXIMUM	.061

Intensity Values in Foot-Lamberts Used for Indirect Red

TABLE II

MINIMUM	.003
NORMAL	.020
MAXIMUM	.084

Intensity Values in Foot-Lamberts Used for Red Flood

TABLE III

SUBJECT #1	4.02
SUBJECT #2	4.00
SUBJECT #3	4.00
SUBJECT #4	4.27

Dark Adaptation Thresholds in Log Micro-Micro Lamberts of Four
Subjects Used in the Study

TABLE IV

SOURCE	SQUARES	d. f.	VARIANCE ESTIMATES	F RATIO	P
<u>Between Groups</u>					
Intensity of lighting	2078.38	2	1039.19	16.72	.01
Kind of lighting	70.08	1	70.08		NS*
Phase (Hangar or Flight)	918.75	1	918.75	14.77	.01
Individuals	3274.25	3	1091.42	17.55	.01
<u>Single Interactions</u>					
Intensity of lighting x Individuals	836.12	6	139.35		NS
Kind of lighting x Individuals	442.25	3	147.42		NS
Phase x Individuals	9723.58	3	3241.19	52.13	.01
Kind of lighting x Phase	184.09	1	184.09		NS
Intensity of lighting x Kind of lighting	397.04	2	198.52		NS
Intensity of lighting x Phase	164.62	2	82.31		NS
<u>Triple Interactions</u>					
Intensity of light x Kind of Light x Individuals	302.13	6	50.36		NS
Intensity of light x Phase x Individuals	414.55	6	69.09		NS
Kind of lighting x Phase x Individuals	321.58	3	107.19		NS
Intensity of lighting x Kind of lighting x Phase	28.79	2	14.40		NS
<u>Quadruple Interactions</u>					
Intensity of lighting x Kind of lights x Phase x Individuals	373.04	6	62.17		NS
Total Sums of Squares	19529.25	47			

*NS - Not Significant

VARIANCE TABLE
QUADRUPLE ANALYSIS OF VARIANCE

TABLE V

FIRST NIGHT	.0017
SECOND NIGHT	.001
THIRD NIGHT	.001
FOURTH NIGHT	.0015

Night Sky Brightness in Foot-Lamberts

Taken together, the results of this study can be fairly well summed up by stating that the effects of the present standard Air Force lighting systems on dark adaptation are functions of intensity and not the kind of system employed. Further, the conditions of night-sky brightness and other factors associated with night flying seem to have a greater effect on dark adaptation than the lighting system employed. The fact that dark adaptation thresholds are significantly affected by intensity levels of red light as well as by night-sky brightness of the order reported in this study does not answer the question as to the degree of dark adaptation loss that can be tolerated. Further investigations are planned to gather data relating to dark adaptation thresholds and visibility for dim objects under conditions of night flight.

VI. CONCLUSIONS

1. Indirect red or red-flood instrument panel lighting systems produce no differing effects on levels of dark adaptation.
2. Intensity of red light affects dark adaptation significantly but to an unknown degree in terms of loss of visibility for dim objects.
3. Night-sky brightness conditions of clear, moonless sky affect dark adaptation significantly.

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7. Taylor, A.H., Vision at low brightness levels. Illum. Engng. 1943, 38, 89-98.

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Discussion:

Mr. Fred Brown expressed his interest in Major Cole's experiments and commented that his group was carrying out experiments of a similar nature. Mr. Brown commented that one difficulty in this experimentation is to specify the problem for the subject while he is observing the instrument panel. Mr. Brown wondered if the lowered thresholds found when the observers were in the hangar could be due to the fact that the subjects had little else to do except follow instructions at that time, whereas in flight tests they had a great many other responsibilities.

Maj. Cole agreed that possibly some of the differences between hangar tests and the flight tests were due to this factor.

Mr. Breckenridge asked if controls had been conducted for the time factor--that is, if the two systems had been alternated with respect to which came first.

Maj. Cole stated that controls of this sort had been included.

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THE ACCELERATION OF DARK ADAPTATION BY CONTROLLED RED LIGHT EXPOSURE

Lt. Samuel C. McLaughlin, Jr.

U.S. Naval School of Aviation Medicine

The first report in the American scientific literature of the acceleration of dark adaption by exposure of the eyes to dim red light was under the authorship of Professor Walter R. Miles, of Yale University and this Committee, in 1943. Several months previous to Dr. Miles' publication, a series of secret (now unclassified) reports, put out by the Admiralty Research Laboratory at Teddington, described a similar phenomenon and recommended its utilization in military applications. In the experiments reported independently from both of these laboratories, it was shown that exposure of the eyes to spectrally pure dim red light (that is, spectral red with no admixture of shorter wavelengths) mediated a photosensitization effect of such a nature that dark adaptation actually appeared to proceed more rapidly in the light than in the dark.

In his remarks yesterday evening, Dr. Blackwell gave us a working definition of photosensitization which I may use as a reference point in describing the photosensitization effect reported independently from these two laboratories. The phenomenon now under discussion is, first of all, a latent one: that is, the reduction in threshold takes place after the termination of the red-light exposure period. And secondly, the type of photosensitization I am talking about evidences itself in a reduction of the absolute rather than of the differential or incremental threshold.

In view of the many wartime experiments which dealt with the evaluation of red goggles for pre-adaptation use, it is surprising to find so few which compared red-light exposure with no exposure at all. In fact, in my own survey of the literature, I was able to find only two experimental comparisons of this sort in addition to the two I have already cited. Unfortunately, one of these appears to have employed purple rather than red light--that is, spectral blue combined with spectral red;--and in the other, the brightness level of the red light was about forty times that employed by either Miles or the British investigators. In neither case was the original result confirmed.

The potential military importance of the first finding, as well as its possibilities in the study of the mechanism of dark adaptation, made further experimental evaluation seem advisable; and the experiments which I shall now describe were carried out for that purpose.

Apparatus and Procedure

I shall describe here only a few salient features of the apparatus which was employed and of the experimental procedures which were followed. The adaptometer was designed to give test flashes of constant duration and its test field, which was relatively nonselective in spectral quality, and could be varied in brightness. The retinal area tested was 3.5 degrees of visual angle in diameter, and was centered seven degrees above the fovea. Threshold determinations were made by a psychophysical method of serial exploration.

In the procedure employed during most of these experiments, each subject (after appropriate practice sessions) was given two forty-five-minute experimental sessions with a ten-minute break between them. Light adaptation took place during the first ten minutes of each session. In one of these two sessions (the first for one half of the subjects and the second for the other half), red-light exposure took place for the ten minutes immediately following light adaptation and was followed by ten minutes in the dark. In the other session

of a pair, the subject was in total darkness for the twenty minutes immediately following light adaptation. For both the red-light-exposure sessions and the total-darkness sessions, threshold determinations were made at twenty, twenty-five, thirty, and thirty-five minutes after the end of light adaptation. Thus any reduction in threshold effected by red-light exposure could be detected by comparing the four thresholds of one dark-adaptation session with the four thresholds obtained during the other session of the same pair.

In later experiments, an attempt was made to determine the effect upon the visual threshold of exposure to red light at various times during the course of dark adaptation. The procedure in these experiments again utilized paired dark-adaptation sessions, in which red-light exposure was inserted sometimes into the first session and sometimes into the second.

In some experiments, red-light exposure was effected by the subject's wearing goggles and viewing the light-adapting field under dim illumination. In others, a better control of brightness was obtained by having the subject view a ground-glass screen which was transilluminated by a filter box containing a source, collimating lens, neutral and red filters, and diverging lens. The latter arrangement also permitted the use of interference filters and other filters which could not conveniently be fitted to goggle frames.

All red-light brightness values were obtained by first measuring the brightness of the "white" light without the red goggle or filter, using a Macbeth Illuminometer. The red filter material was then calibrated on a Beckman Model DU Spectrophotometer, its transmission values were weighted by the ordinates of the ICI photopic luminosity curve, and the photopic transmission thus computed for the filter was applied to the white-light brightness in order to arrive at the effective red-light brightness. All visual photometric measurements were made at photopic levels of illumination.

Results

The experiments which I have performed to date, and which I have just described, are of a preliminary nature, and were designed (a) to determine whether or not there existed a red-light photosensitization effect of such magnitude that further investigation of it might be of practical and theoretical value, and (b) to provide information which might be useful in setting up experiments to explore that phenomenon in more detail. I shall therefore present the evidence which I have for the existence of this effect, as well as the few statements which I feel justified in making regarding its characteristics.

The data which I have published in a Project Report from the Naval School of Aviation Medicine at Pensacola are as good as any that I have so far obtained for demonstrating the existence of a red-light photosensitization effect. These data were obtained using the experimental procedure already described in which red light exposure takes place immediately following light adaptation. During the red-light exposure period, the subject wore goggles containing Corning #2030 glass, and viewed the light-adapting field under dim illumination. The red light to which the subject was thus exposed had a brightness of about .0056 ft-L. Corning #2030 glass transmits practically no incident radiant energy below 6400 A.U., and 50% at about 6650 A.U. These same data will also serve to illustrate the amount of threshold reduction which I have been able to bring about by red-light exposure.

These data, averaged in terms of $\log \mu\text{L}$, showed that the mean of the four thresholds was lower following red-light exposure than following a similar period in total darkness. This was true for nine of the ten subjects, and the mean reduction in threshold was .151 $\log \mu\text{L}$. However, averaging them in terms of μL rather than $\log \mu\text{L}$ gave a mean reduction in threshold of 190 μL , which is equivalent to 2.28 $\log \mu\text{L}$.

This fifteen-fold increase in the apparent magnitude of the reduction in threshold, (i.e., .151 to 2.28), merely as a result of the shift from log to linear scale, is typical of every similar set of data which I have analyzed in this fashion, and illustrates the importance of this particular choice of scale.

There are arguments for using either scale. One may, for example, regard the log scale as an approximation to a psychophysically linear scale, and from this point of view the question of the propriety of summing and dividing logarithmic values in order to obtain a mean is irrelevant. On the other hand, the thresholds which are here being averaged show very little progressive lowering during the course of a single dark-adaptation session, thus tending to obviate the need for a modification of the μL scale.

Examination of the mean reduction in threshold in terms of μL for each of these ten subjects shows that six of them lie between 25 and 57 μL , while the other four are well outside of this range, one being as high as 1274 μL . A good estimate of the reduction in threshold to be expected from red-light exposure under the conditions specified is the mean of these six data, or about 37 μL . A less controversial method of answering this question of the magnitude of the photosensitization effect is by the use of a method of constant stimuli, so that temporal integration may be accomplished by a summation of response frequencies rather than by an averaging of threshold values.

In lieu of such data, I have considered the quantitative aspect of the photosensitization effect in some detail because of the possibility that the amount of threshold reduction which can be obtained by this technique may be important in deciding upon the usefulness of the method in certain military applications.

I shall now list such few other statements regarding the parameters of the photosensitization effect as I feel are justified at the present time. In so doing, I shall refer to the two previous sources of information on this topic (Miles' report and the British papers) as well as to some unpublished data of my own.

1. The British data support the hypothesis that the effect is mediated primarily by infra-red rather than by visible radiant energy; my own data, on the other hand, indicate that the most effective radiations lie between 6000 and 7000 A.U.

2. I have obtained the effect, using Corning #2030 glass, for several red-light brightnesses, between .005 and .02 ft-L. With a red-light brightness of two ft-L, the effect did not appear.

3. I have worked with about thirty different subjects. All of these subjects showed the effect at one time or another; most of them showed it in every experimental session of the type which I have described as the best demonstration of the effect. Two or three rarely showed a lowering of the threshold following red-light exposure. The ten subjects whose data appear in the Project Report which I have already published were typical in this respect of all the groups of subjects which I have since used: All but one of them showed the photosensitization effect.

4. The effect upon the visual threshold of a 3-10 minute period of red-light exposure during the course of dark adaptation is something that requires (and merits) extensive investigation. My data indicate that such an exposure period at any time during the initial rapid drop in the dark-adapted threshold has about the same effect as if it immediately followed light adaptation. Miles obtained the full photosensitization effect with red-light exposure taking place throughout the course of a 35-minute dark-adaptation period except during threshold determinations. I have not so far been able to duplicate this result.

5. In several of my experiments, I have come across an extremely interesting phenomenon which I have labelled "secondary photosensitization." This occurred when a subject had been in the dark for 40-60 minutes and was given a three-minute red-light exposure period. Immediately following this exposure period, the subject's threshold dropped--in some cases by almost a full log unit below any previous value--and then returned to the former level after about five minutes. I have been able to obtain this effect only occasionally, so that its existence is extremely difficult to demonstrate in a convincing manner. I know of no confirming evidence from other sources. If it is a real effect, it is undoubtedly related in some way to the primary photosensitization effect which has been the principal subject of my investigations.

6. Miles' subjects read magazines and did homework during the red-light exposure periods, and still obtained a greater reduction in subsequent dark-adapted threshold than my subjects have been able to achieve with any brightness level of red light. I have not yet been able to create a red-light exposure situation which would lower the observer's threshold while at the same time giving him enough light to read by. I have done many experiments in which the subjects had enough red light so that they could read and their subsequent threshold was as low as if they had spent a corresponding period in total darkness, but in no case did I obtain reliable reductions in threshold by such means. I think that this result can be obtained, but I cannot report it at the present time.

7. The British reports presented evidence showing that the photosensitization effect persisted for at least ninety minutes after the end of an initial 20-minute red-light exposure period. I have not checked this result.

Discussion

I have used the term "photosensitization effect" in a purely descriptive sense, and I have intended to imply nothing about the mechanism underlying this observable phenomenon. I have nothing to say on that subject at the present stage of my experimentation.

I have made several statements regarding certain parameters of the phenomenon under discussion without going into full detail regarding the data on which those statements are based. As I have already indicated, the data I now have are from exploratory experiments. I expect to be able to publish more definitive and quantitative results within a few months. I have presented these preliminary results only in the interests of disseminating as much information as I have about a phenomenon which may be of value in military situations where the sensitivity of the dark-adapted eye is a critical factor.

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Discussion:

CDR. Farnsworth stated that he had been asked by Dr. Dimmick to present a report of experimental tests of red light photosensitization which were prompted by preliminary reports of Lt. McLaughlin's work. CDR. Farnsworth noted that the New London group had been interested in the question of red light photosensitization during the war but had decided that the effect did not exist. Indeed, Dr. Walter R. Miles had come to share this conviction after originally believing them to be such an effect. In this connection, CDR. Farnsworth expressed appreciation to Lt. McLaughlin for calling attention to this problem again and thanked him for his kindness in making his research results available before publication, thus making it possible for the New London group to design their related experiments.

The New London group found it comparatively easy to run tests on this question, since subjects and equipment were available for tests of dark adaptation under various conditions. The study which the New London group conducted involves conditions which, for the most part, are similar to those involved in Lt. McLaughlin's study. The differences in physical experimental conditions are minor and it seems unreasonable to suppose that they affected the results materially. The differences were: The use of a 2° test object instead of the slightly smaller one used by Lt. McLaughlin; the use of a different stimulus point on the retina; the use of a luminance of .006 rather than .0056 foot-Lamberts.

Two methodological differences were involved which may have some significance. First of all, the New London tests were performed on a body of trained subjects. These subjects had already made dark adaptation measurements with the apparatus to the extent that they had reached stabilized criteria. Examination of Lt. McLaughlin's data shows that the data were quite scattered, suggesting either that the subjects were not very well trained or that they had not reached stabilized criteria. The second methodological difference involves the method of measuring thresholds. The method developed by Dr. Dimmick's sections is a modified method of constant stimulus. This method permits 300 observations per experimental session. These results can be handled statistically and previous experiments utilizing this technique have demonstrated the great stability of the values obtained in this manner. In contrast, the psychophysical method utilized by Lt. McLaughlin gives comparatively few measurements and seems to give considerable variability from measurement to measurement.

The time schedule of red and white light adaptation duplicated Lt. McLaughlin's conditions precisely.

Seven subjects were used in all. Two subjects showed reversals to the sensitization effect reported by Lt. McLaughlin. Of the five who showed the effect, none showed a greater effect than a difference in log threshold of .05.

Following these tests, the New London group made a study under conditions suggested by the photosensitization concept. The original design was based upon the notion that the photosensitization effect of red light would be a delayed effect. For this reason, ten minutes of dark adaptation were interposed in the original design between the red light stimulation and the testing period. It occurred to the New London investigators to question why a delayed effect was to be expected. It seemed reasonable that a photosensitization effect should show up immediately following stimulation by red light. To test this hypothesis, experiments were run in which the test period immediately followed the red light stimulation. It would seem that the maximum photosensitization effect would be expected to be found under these conditions. Three subjects were used in all. Of these, two showed differences in the wrong direction and the third showed a difference of .03 in the log threshold.

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CDR. Farnsworth concluded that, so far as the New London tests were concerned, there was no evidence of red light photosensitization. He expressed the hope that this unofficial report of the New London test results would be useful to Lt. McLaughlin in connection with the design of his future experiments.

Lt. McLaughlin requested that the following reply be read into the Minutes:

"I wish to thank LCDR. Farnsworth for presenting this interesting and valuable data. Although I was not aware that these experiments had been carried out or that the results were to be presented at this time, I did know that such experiments had been planned for some time at the New London Laboratory. Several months ago, in fact, I discussed these experimental plans with Mr. Smith of that laboratory, and it was apparent to me (and, I thought, to Mr. Smith) that the projected experiments did not by any means constitute a replication of my own experiments.

"I submit that the difference in psychophysical procedure, which LCDR. Farnsworth regards as insignificant, is in fact an important difference between the two experiments. My subjects received only a few test flashes--and most of these subliminal--once every five minutes; Mr. Smith's subjects received one test flash every three seconds for the entire fifteen-minute test period, and his statistical technique required that at least half of these be supraliminal. Therefore, wholly aside from any effect of the difference in psychophysical procedure per se, (and this can be evaluated only by experimentation), Mr. Smith's procedure was such that any effect of red light might well be cancelled out by the testing procedure.

"With regard to LCDR. Farnsworth's criticism of my data as having excessive variability, I submit that this also is largely a function of the difference in psychophysical procedure. Periodic fluctuations in the dark-adapted visual threshold have been described by numerous investigators and were the subject of an investigation by Lee, Finch, and Pounds (Amer. J. Physiol., 143, 6-10, 1945). It is obvious that such fluctuations, while being averaged out by a constant-stimulus technique, would contribute to the variability of the results with the use of a technique such as mine, which involved discrete threshold determinations. I would therefore argue that the lack of variability in Mr. Smith's data is as artifactitious as the non-appearance of the red-light photosensitization effect."

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EFFECTIVENESS OF RED LIGHT ON DARK ADAPTATION

Walter R. Miles
Yale University

Scientific and practical interest in the relative effectiveness of lighting of different colors on dark adaptation came to a focus ten years ago under the exigencies of military needs. Red as the most appropriate lighting for instrument panels of military planes used for night missions was recommended by researchers in aviation medicine in 1940.¹ It was in this connection that the present writer a little later extended the problem to the study of the possible usefulness of red dark adaptation goggles. Our tests at Yale late in 1941 gave results for the red goggles apparently equivalent to those achieved by the ordinary darkness routine, in which no goggles were involved. These findings were immediately communicated to various military activities in the United States, Canada and England by letter, together with sample sets of the goggles with the suggestion that they might be tried out.² Somewhat later a short paper on this subject was prepared for a symposium.³ A work-up of data then on hand appeared to support the conclusion that our threshold results after adaptation with red light were on the average a little lower than those following the darkness routine. At the time of preparing this report for publication it seemed appropriate to record this fact. Also, the writer was cognizant of similar results claimed by R. W. Cheshire, Superintendent at the British Admiralty Research Laboratory, Teddington, Middlesex. In a number of Admiralty research reports, Confidential at the time, beginning in April, 1942, and including six or seven consecutive reports, up to November, 1942, Cheshire and his associates claimed a positive advantage for red light in comparison with darkness. In the summary of the latter report one reads: "It is shown that in red light of suitable intensity some type of adaptation proceeds more rapidly than in total darkness. Also this stimulating effect continues even after the red light has been cut off. Similar results are reported for orange light though the stimulating effect is smaller."⁴

A recent study of the problem by McLaughlin has just appeared.⁵ This investigation reports data on 10 subjects. Dark adaptation thresholds were obtained after the subjects had, in one experiment, been 20 minutes in total darkness, and in another experiment, after they had been 10 minutes in red light followed by 10 minutes in darkness. The results reported give the average threshold for all subjects as 0.151 log. μvL . lower following the combination of red light exposure and darkness than for a 20 minute period in darkness. The author states: "It is concluded that at least a part of the total process of visual dark adaptation proceeds more rapidly in the presence of red light than in darkness, and this conclusion is shown to be in accord with other published experimental findings."

McLaughlin, in his report, informs us that the pre-adaptation brightness for his subjects was 130 footlamberts; that the test-patch subtended 1.5° visual angle, and was centered 7° above the fovea; a dim red fixation point was used; the thresholds were for violet light; a pendulum-type shutter in the adaptometer gave flashes of .20 sec. duration. The two dark adaptation routines were carried out on the same subjects, one routine following the other on the same day. Some subjects had the 20 min. of darkness first, others had this second. The report happily also reproduces in Table 2 the individual threshold data. Under both routines, red light and darkness, thresholds were determined on each subject at the end of 20, 25, 30, and 35 min. Comparison of the 20-min. threshold scores yields a mean dif-

ference of -0.126 , the 25-min. mean difference is -0.176 , at 30 min. it is -0.187 , and for 35 min. we find $-0.116 \mu\text{L}$. All four sets of thresholds give means for the 10 subjects which seem to favor the use of red light. But it might be expected that this difference would be maximal at 20 min. for this experiment, and as the subjects remained in darkness would become smaller in the threshold tests made at 25, 30, and 35 min. However, an opposite tendency appears to be present in these data particularly in the 25 and 30 min. thresholds. The explanation is not evident. (See later discussion of Tables 5 and 6 in this paper).

The threshold values reported by McLaughlin appear to be high even when one remembers that the test-patch had a subtense angle of 1.5° . There comes a change at the 35-min. measurement period. His average curve for the darkness routine flattens out in terms of the mean values at 30 and 35 min. Five subjects show lower thresholds at 35 min. and 5 gave higher thresholds. On the other hand, the 35 min. values for the red light routine average 0.075 higher than at the 30-min. period. This sudden change in the direction of the curve is not easily explained. The contrast between red and dark in McLaughlin's published data is more striking if based on the average for the 20-, 25-, and 30-min. scores (omitting the 35-min. scores), and on this basis shows a mean difference of 0.163 , $P = 0.01$.

Yale Red Goggle Data, 1941 & 1942

In anticipation of the discussion which will be aroused by the results and conclusions Lt. McLaughlin has presented in his publication of May 1952, it seemed appropriate to present more fully the experimental evidence for the effectiveness of red goggles on dark adaptation secured at Yale in 1941 and 1942 and also a heretofore unreported study made late in 1943 by the method of comparative monocular adaptation. The red goggle of 1941-1942 was one portion of a fairly comprehensive program conducted during those years on dark adaptation.⁶

For more complete details of some aspects of our first studies on red goggles the reader must be referred to the earlier publication.⁷ It will be sufficient here to note that our red goggles were made of Corning HR Pyrometer Shade Red, New Glass Code, No. 2403, 2 mm. thick, 2 inch diameter, and polished. These discs had a photopic transmission of 3.80%, and scotopic transmission, 0.246%. After pre-light-adaptation to 1500 ml. for 3-1/2 to 4 minutes by use of the Hecht-Schlaer adaptometer, the subjects put on the goggles and wore them for 25 min. while seated in a laboratory waiting-room under an illumination of 9 ml. Books and magazines were provided convenient for the subjects during the period of wearing the goggles and also people were moving about. At the end of 25 min. and while still wearing the goggles the subjects went with the technician to the measurement room, containing the adaptometer (Hecht-Schlaer No. 8). This room was well-lighted by a standard 16" opalescent bowl, ceiling fixture. The walls of the room were dark. After the subject was seated in front of the adaptometer ready to observe, the ceiling light was turned off, and then the subject removed the red goggles, having usually had them on for from 27 to 30 minutes. Threshold measurements were begun immediately.

In the earlier paper graphic representation of results were presented for six subjects.

Here, in Table 1, we present the results for these same six subjects and two others, tabulated in such a manner as to give the mean threshold values for the period 28-38 minutes after the completion of pre-light-adaptation. The "darkness routine" here represents thresh-

Table 1

Reanalysis of first data secured in 1941 on effectiveness of red goggles as an alternate technique for securing dark adaptation. This table of eight paired replicates for terminal thresholds to violet light includes some data not previously published.*

Red Goggle Routine			Darkness Routine		Differences DR-RGR
Date	Case	Mean Threshold (log $\mu\text{L.}$)	Date	Mean Threshold (log $\mu\text{L.}$)	
11/3/41	B. W.	3.625	10/28/41	3.878	+0.253
11/3/41	R. D.	3.234	6/16/41	3.261	+0.027
11/4/41	E. L.	3.235	10/16/41	3.295	+0.060
11/4/41	B. W.	3.562	10/27/41	3.812	+0.250
11/10/41	J. G.	3.062	10/27/41	3.303	+0.241
11/11/41	E. L.	3.234	10/23/41	3.480	+0.246
11/11/41	R. G.	2.868	10/28/41	2.787	-0.081
11/12/41	G. B.	3.287	10/23/41	3.449	+0.162
N = 8		M. = 3.263	M. = 3.408		M. Diff. =+0.145
					P = 0.04

*These 8 pairs of measurements were made with the aid of Hecht-Schlaer Adaptometer No. 8 using Corning violet filter No. 511 (Old Glass Code; No. 5113 New Glass Code), 2° test field centered 7° nasally for the right eye with 1/5 sec. exposures following preadaptation to 1500 ml. for 3-1/2 to 4 min. The red goggles used here were those previously described (3) made of Corning: H. R. Pyrometer Shade Red, New Glass Code no. 2403, Old Glass Code no. 241, 2mm. thick, polished discs with cut off at 620 m μ . mounted in Cover's "Nod and Shake" rubber goggles. The illumination in the room where the subject sat for 25-30 min. was 9 ml. and the terminal threshold values given are the means of those made between 28 and 38 min. after the completion of pre-adaptation.

hold values taken from complete series of dark adaptation measurements whose beginnings started immediately after the pre-light-adaptation. We have entered in Table 1 the "terminal threshold values" representing the mean threshold for the time period 28-38 minutes, as also for the red goggle routine. Bearing in mind that the test field was 2° rather than the more usual 3° test-patch, we find the mean for this red goggle routine to be 3.263 log. $\mu\text{L.}$, while the mean for the darkness routine is 3.408, that is, higher by a mean difference of +0.145, $P = 0.04$. All of these eight subjects were among those that we were using fairly frequently for measuring dark adaptation in different connections. For this comparison we chose for each of the eight subjects their individual lowest regular dark adaptation curve secured under the conditions represented by the red goggle routine, i.e. pre-light-adaptation to 1500 ml. for 3-1/2 to 4 min. and 2° test-patch.

A second set of what we believe to be comparable data and involving many of the same subjects is presented in Table 2, in which we put together nine paired replicates for all of whom pre-adaptation to 1500 ml. light was not a part of the routine. The 2° test-patch was used and thresholds were averaged for the same interval after the beginning of each routine, that is, 28-38 minutes. Both mean thresholds in Table 2 are appropriately lower than those in Table 1. The mean for the red goggle routine is 3.002 log. $\mu\text{L.}$ and for the darkness routine, 3.266, the mean difference is +0.264, $P = 0.02$.

Table 2

Analysis of red goggle adaptation data secured in 1941 but not previously published. The conditions were the same as those described for the 8 pairs (Table 1) except that preadaptation to 1500 ml. light was not used as a part of the routine.*

Date	Case	Red Goggle Routine Mean Threshold (log μ L.)	Date	Darkness Routine Mean Threshold (log μ L.)	Differences DR-RGR
10/30/41	M. M.	3.351	10/24/41	3.338	-0.013
10/30/41	E. L.	2.970	6/4/41	3.455	+0.485
10/30/41	G. B.	3.116	10/16/41	3.392	+0.276
10/31/41	R. D.	3.138	5/23/41	3.350	+0.212
10/31/41	B. W.	3.303	10/29/41	3.777	+0.474
11/4/41	R. J.	2.584	10/21/41	2.868	+0.284
11/5/41	J. G.	2.951	10/14/41	3.383	+0.432
11/6/41	R. J.	2.571	10/24/41	2.547	+0.024
11/7/41	R. D.	3.031	7/15/41	3.285	+0.254
N = 9		M. = 3.002		M. = 3.266	M. Diff. = +0.264 P = 0.02

*The terminal threshold values given are the means of those made between 28 and 38 min. after starting the respective test routines on each subject.

The data represented in Tables 1 and 2 were in hand when our red goggle results were first announced privately to the military services with the suggestion that the accompanying sample sets be tried out. In December of 1941 prompt steps were taken to make up some trial service goggles for dark adaptation purposes using plastic lenses mounted in sponge rubber frames designed by Captain Leon D. Carson, MC, USN. Early in January, 1942 the Polaroid Corporation supplied the Yale Laboratory with samples of these goggles, designated as DA-2 and DA-3. We set about making trials with these under similar conditions to those used before, except for using a 3° test field in this comparison. The results are presented in Table 3. Fifteen paired replicates, some of them representing more than one set of trials on the same subject, show a mean for the red goggle routine of 2.243 log. μ L. The mean for the darkness routine, which again is full dark adaptation curve measurements, but including only the terminal threshold portion, is 2.390; the mean difference, +0.147, shows $P = 0.01-0.005$. Having thus found that the recently designed Service dark adaptation goggles, DA-2 and DA-3, which had photopic transmission of 8-12%, gave laboratory results quite similar to those previously found with our experimental goggles, there seemed for the time being nothing further of pressing experimental importance to be done about this matter. The next thing was to recommend wide distribution and use of the red goggles, and proper routines in connection with wearing them. These tests with the Service goggles had again given slightly better results for the red goggle compared with those involving the usual darkness routine.

Some British Admiralty Data

Results published in experimental laboratory reports from the Admiralty Research Laboratory at Teddington involved the use of the Admiralty Adaptometer, which ordinarily gave a range of threshold scores at the end of 30 min. of "Grades" 6 or 7 to 12 or 13. The lower the grade the keener the night vision. In one of their reports, issued 9 October 1942, there is a collection of individual score data in their Table 1, where the "normal half-hour grade," or scores, are given for 24 subjects, 19 men and 5 women.⁸ Score range is from

Table 3

Paired replicates for terminal dark adaptation thresholds to violet light after use of red goggles versus darkness routine.*

Date	Case	Red Goggle Routine Mean Threshold (log μ L.)	Date	Darkness Routine Mean Threshold (log μ L.)	Differences DR-RGR
1/5/42	L. T.	2.311	1/12/42	2.356	+0.045
1/9/42	L. T.	2.168	1/17/42	2.245	+0.077
1/9/42	B. W.	2.572	1/13/42	2.923	+0.351
2/12/42	L. T.	2.080	1/14/42	2.053	-0.027
2/13/42	J. G.	2.151	2/11/42	2.462	+0.311
2/13/42	W. H.	1.934	1/26/42	2.208	+0.274
2/14/42	L. K.	2.091	2/19/42	2.510	+0.419
2/17/42	E. L.	2.326	2/10/42	2.488	+0.162
2/20/42	M. P.	2.220	2/19/42	2.159	-0.061
2/21/42	L. T.	2.363	1/20/42	2.424	+0.061
2/25/42	G. B.	2.350	12/3/42	2.790	+0.440
2/25/42	L. T.	1.989	2/20/42	2.172	+0.183
2/27/42	M. P.	2.361	2/16/42	2.475	+0.114
3/18/42	D. W.	2.372	3/13/42	2.376	+0.004
4/1/42	R. D.	2.355	4/3/42	2.216	-0.139
N = 15		M. = 2.243	M. = 2.390		M. Diff. = +0.147
					P = 0.01 -0.005

* These 15 pairs of observations were all made on Hecht-Schlaer Adaptometer No. 8 supplied by O. C. Rudolph using Corning violet filter No. 511 (Old Glass Code; No. 5113 New Glass Code), 3° test field centered 7° nasally for the right eye with 1/5 sec. exposures following preadaptation to 1500 ml. for 3-1/2 to 4 min. The red goggles had plastic lenses designated DA2 and DA3 and were supplied by Polaroid Corporation. The goggles were put on immediately following light preadaptation and were worn without interruption for 25 to 30 min. while the subject sat reading magazines by Mazda lamp illumination of 9 ml.

7 to 12, and the mean for the 24 subjects is 9.0. For the same group there are threshold scores following dark adaptation by wearing deep red (Chromex 2033) goggles for 20 minutes in an external illumination of 7.7 footcandles. These goggles had a photopic transmission of 3.9%. Following adaptation to light of 7.7 footcandles for some minutes, the red goggles were worn for 20 minutes. The subjects were then in darkness for 10 minutes after which another threshold grade determination was made. Individual scores ranged from 6.5 to 10, and the mean was 8.2. The difference between the mean scores is thus 0.8 grades on the Admiralty Adaptometer. This difference, according to the present writer's computations, has a level of confidence value, $P = 0.01$.

Yale Experiments on Comparative Monocular Dark Adaptation

During the latter half of October and extending until the 10th of December in 1943 comparative monocular experiments in dark adaptation involving the use of red goggles were conducted.⁹ Two problems were undertaken. The first was to study the results from adapting one eye to red light and the other to blue light. It was expected on theoretical grounds that the thresholds for the eyes exposed to red light for 25 to 30 min. would be 0.5 to 1.0 log. units lower than those for the eyes exposed to blue light. The second study involved adaptation of one eye to red light and the other to complete darkness by means of an opaque screen placed in the goggle. Here it was expected on the basis of our previous results that the red goggle values might be as low as those for darkness (opaque screen).

Apparatus and Procedure

The arrangements for Series 1, red-blue, monocular adaptation tests, were similar to our earlier work. The goggles were made of Corning 2" polished discs; one-No. 5551-blue, 5 mm. thickness, 4% photopic transmission; the other disc was Corning No. 2403, the same as used in our earlier red adaptation goggles, except this one was 5 mm. in thickness and had a photopic transmission of 3.5%. The frames in which these discs were mounted were those used for welders' goggles and made a neat fit with the nose, brow, temple, and cheek of the subject, but unfortunately they fogged badly. The arrangements and routine for pre-adaptation to light were carried out in the same room in which subjects wore the goggles for the prescribed 25 min. A metal box, 7" deep and with a window 10" x 13", contained a reflector and a 200-Watt unfrosted Mazda bulb. The filament was at the geometric center of the reflector and the window was covered with one sheet of double thickness ground glass and one sheet of double thickness opal glass, to achieve a fairly even distribution of the light. For a diameter of 7" near the center of the window the brightness measured 693 ml. In the pre-adaptation period the subject sat with his eyes level with the center of the lighted window and 24" away from it. He looked from one side to the other of the window, and from near the top to the bottom, for 3 min. changing fixation so as not to experience a troublesome afterimage. The central portion of the visual field of both eyes was very systematically light-adapted, although the level of adaptation was less profound than when using the Hecht Adaptometer for this purpose. Immediately after the light adaptation period of 3 min. the subject put on the experimental goggles and kept them on for 25 min. by the clock. Then with the goggles still on he passed through a lighted hallway to the adaptometer room. The illumination of the room in which they sat during this 25 min. was by two ceiling fixtures, opal bowls, 15" in diameter, each containing a 200-Watt clear Mazda lamp. The measured light on the table-top by the subject was 7.8 ml. This table on which the pre-adaptation light box was placed also had on it books and papers and magazines. Subjects sat in a large rocking-chair placed below one ceiling light and next to the table. The brightness measured at the subject's lap when in the chair was 5 ml. The table was brighter because it received somewhat more reflection from the wall at the end of the room. In the darkroom where the Hecht-Schlaer Adaptometer was located the arrangements and conditions were similar to those previously used in our dark adaptation experiments for testing the red goggles. The room was well-lighted when the subject came in wearing the goggles. He took his place for observation at the Adaptometer, then the ceiling light was put out, after that the subject removed the goggles and immediately began making observations for determining threshold levels. A 3° test-patch was used, centered 7° below a small red fixation point. Alternate thresholds were made on the right and left eyes of the subject, beginning as promptly as possible after the goggles were removed and continuing for 18 min.

In the second set of experiments on monocular dark adaptation the arrangements were similar to those just described except the goggles were modified by removing the blue glass and in its place fitting an opaque disc through which no light could pass. The same red Corning No. 2403 discs were used for the other eye of each set of goggles. One set had the red goggle in place for the left eye and the opaque screen for the right, the other set of goggles had the opposite arrangement.

Results for Red-Blue Monocular Dark Adaptation

With trained subjects who were college students it was possible to determine thresholds quite promptly following removal of the dark adaptation goggles. Usually one or two thresholds could be established for each eye within a 2-min. period. This was true for 9 of our 10 subjects. The tenth subject proved so slow we could not secure right and left eye data for each successive 2-min. period, and hence have omitted his results from Table 4. The individual threshold averages for red and blue separately are grouped in nine 2-min. periods for comparison. Beginning with I in the upper left of Table 4 we find for the first

Table 4

Paired replicates for comparative monocular dark adaptation thresholds after wearing a red goggle over the left eye and a blue goggle over the right eye for 30 minutes. Values given in log, micro-micro-lamberts.*

Cases	I Time: 1-2 min.			II Time: 3-4 min.			III Time: 5-6 min.		
	Red	Blue	Diff.	Red	Blue	Diff.	Red	Blue	Diff.
F. M.	3.04	4.22	+1.18	2.60	3.39	+0.79	2.47	3.10	+0.63
J. S.	2.77	3.69	+0.92	2.49	3.28	+0.79	2.54	3.00	+0.46
C. O.	2.65	3.43	+0.78	2.60	3.20	+0.60	2.90	3.10	+0.20
E. S.	2.94	3.75	+0.81	2.55	3.43	+0.88	2.44	2.85	+0.41
S. R.	2.44	3.44	+1.00	2.44	2.90	+0.46	2.21	2.77	+0.56
F. W.	2.54	3.91	+1.37	2.44	3.44	+1.00	2.41	2.94	+0.53
F. G.	2.77	3.10	+0.33	2.49	2.64	+0.15	2.44	2.50	+0.06
B. B.	2.37	3.59	+1.22	2.23	2.52	+0.29	2.12	2.57	+0.45
G. M.	2.94	3.59	+0.65	2.97	3.25	+0.28	2.60	3.00	+0.40
N = 9 Ms,	2.718	3.636	+0.918	2.534	3.117	+0.583	2.459	2.870	+0.411
		P = 0.01			P = 0.01			P = 0.01	
Cases	IV Time: 7-8 min.			V Time: 9-10 min.			VI Time: 11-12 min.		
	Red	Blue	Diff.	Red	Blue	Diff.	Red	Blue	Diff.
F. M.	2.50	3.27	+0.77	2.29	2.93	+0.64	2.44	2.94	+0.50
J. S.	2.80	2.89	+0.09	2.37	2.60	+0.23	2.50	2.75	+0.25
C. O.	2.57	2.90	+0.33	2.52	2.90	+0.38	2.34	2.78	+0.44
E. S.	2.36	2.54	+0.18	2.04	2.35	+0.31	2.34	2.84	+0.50
S. R.	2.04	2.57	+0.53	2.29	2.60	+0.31	2.12	2.44	+0.32
F. W.	2.27	2.67	+0.40	2.34	2.67	+0.33	2.21	2.62	+0.41
E. G.	2.50	2.50	+0.00	2.41	2.49	+0.08	2.34	2.54	+0.20
B. B.	1.97	2.36	+0.39	2.18	2.52	+0.34	2.02	2.20	+0.18
G. M.	2.52	2.82	+0.30	2.57	2.68	+0.11	2.24	2.50	+0.26
	2.392	2.724	+0.332	2.334	2.636	+0.302	2.283	2.623	+0.340
		P = 0.01			P = 0.01			P = 0.01	
Cases	VII Time: 13-14 min.			VIII Time: 15-16 min.			IX Time: 17-18 min.		
	Red	Blue	Diff.	Red	Blue	Diff.	Red	Blue	Diff.
F. M.	2.44	2.87	+0.43	2.32	2.98	+0.66	2.50	2.83	+0.33
J. S.	2.32	2.70	+0.38	2.28	2.49	+0.21	2.36	2.50	+0.14
C. O.	2.37	2.70	+0.33	2.55	2.65	+0.10	2.32	2.52	+0.20
E. S.	2.36	2.57	+0.21	2.28	2.62	+0.34	2.31	2.67	+0.36
S. R.	2.21	2.44	+0.23	2.28	2.40	+0.12	2.21	2.37	+0.16
F. W.	2.23	2.57	+0.34	2.21	2.55	+0.34	2.27	2.44	+0.17
E. G.	2.49	2.45	-0.04	2.59	2.50	-0.09	2.44	2.43	-0.01
B. B.	2.12	2.34	+0.22	1.86	2.18	+0.32	2.00	2.15	+0.15
G. M.	2.60	2.50	-0.10	2.13	2.40	+0.27	2.28	2.37	+0.09
	2.349	2.571	+0.222	2.277	2.530	+0.253	2.299	2.476	+0.177
		P = 0.02			P = 0.01			P = 0.01	

* These 9 sets of observations were made on Hecht-Schlaer adaptometer No. 8 using Corning violet filter No. 5113, 3° test field centered 7° below a small red fixation point following pre-adaptation to 693 ml. for 3 min. The goggles were made of Corning 2 inch polished discs, one No. 5551 blue, 5 mm. thickness, 4 per cent photopic transmission and one No. 2403 red, 5 mm., 3.5 per cent photopic transmission.

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two minutes that the mean threshold for the 9 subjects for the eye that had been exposed to red light was 2.718 and for the other eye exposed to blue light the comparable mean was 3.636 log. $\mu\mu\text{L}$. In each of the 9 subjects the threshold for the blue light was higher than for red, giving a mean difference of +0.918 log. $\mu\mu\text{L}$, $P = 0.01$. It will be noted that the mean thresholds for blue are dependably higher than those for red throughout the table and that the mean difference between the two decreases fairly regularly in successive 2-min. periods. There is a minor reversal between periods VII and VIII. The individual subject differences between red and blue are characteristically plus-differences. In the first 12 min. there was only one exception, subject E.G. in IV had the same threshold value, 2.50, for both blue and red. Two minus-differences appear in period VII, one in VIII, and one in IX. The P-values throughout the table are all less than 0.01. With the exception of period VII where $P = 0.02$, the mean differences show $P = 0.01$.

This experiment on comparative monocular adaptation to red and blue light, confirmed predictions and is germane to discussions about the appropriateness of blue light as safety light aboard ship. The practical military implications of this experiment are obvious. Military or other personnel, if they must work in a faint light, tend to choose either blue or white, because they can see better than with red light. By the same token, they fail to become as well dark-adapted as they might in red illumination, and, if some of the blue light escapes it is a stronger and more easily discovered cue for the enemy than red light would be.¹⁰

Table 5

Paired replicates for comparative monocular dark adaptation thresholds after wearing a red goggle over the left eye and an opaque screen over the right eye for 30 minutes. Values given in log. micro-micro-lamberts.*

Cases	I Time: 1-6 min.			II Time: 7-12 min.			III Time: 13-18 min.		
	Red	Opaque	Diff.	Red	Opaque	Diff.	Red	Opaque	Diff.
S.R.	2.82	2.74	-0.08	2.55	2.63	+0.08	2.49	2.52	+0.03
F.B.	2.70	2.82	+0.12	2.89	2.96	+0.10	2.59	2.75	+0.16
L.T.	2.86	2.50	-0.36	2.73	2.58	-0.15	2.56	2.63	+0.07
H.M.	3.17	2.73	-0.44	2.71	2.62	-0.09	2.58	2.59	+0.01
B.W.	2.68	2.48	-0.20	2.79	2.47	-0.32	2.66	2.51	-0.15
H.C.	2.91	2.75	-0.16	2.60	2.61	+0.01	2.40	2.48	+0.08
E.G.	2.56	2.38	-0.18	2.51	2.36	-0.15	2.43	2.46	+0.03
A.R.	2.51	2.41	-0.10	2.30	2.35	+0.05	2.39	2.32	-0.07
C.R.	2.52	2.68	+0.16	2.55	2.65	+0.10	2.48	2.42	-0.06
F.T.	3.31	3.06	-0.25	2.79	2.65	-0.14	2.54	2.41	-0.13
A.K.	2.67	2.77	+0.10	2.46	2.41	-0.05	2.37	2.40	+0.03
E.W.	2.93	2.43	-0.50	2.62	2.47	-0.15	2.59	2.46	-0.13
F.M.	2.56	2.55	-0.01	2.09	2.13	+0.04	2.24	2.20	-0.04
J.S.	2.87	2.66	-0.21	2.56	2.65	+0.09	2.42	2.53	+0.11
D.G.	3.07	2.90	-0.17	2.76	2.77	+0.01	2.79	3.05	+0.26
M.H.	2.82	2.64	-0.18	2.59	2.38	-0.21	2.41	2.33	-0.08
N = 16 Ms	2.810	2.657	+0.153	2.594	2.537	+0.057	2.491	2.504	-0.013
			P = 0.01			P = 0.05			P = 0.05

*Measurements taken with the aid of the Hecht-Schlaer adaptometer No. 8 using Corning violet filter No. 5113, 3° test field centered 7° below a small red fixation point. The adaptation goggles featured a red Corning No. 2403 disc for one eye and an opaque cardboard disc for the other. The eyes were tested alternately as rapidly as possible after the goggles were removed. The subjects were pre-adapted to 693 m μ for 3 min.

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Results for Red-Opaque Monocular Dark Adaptation

As is to be expected from the results in Tables 1, 2, and 3 of this paper, the thresholds after red adaptation with one eye and darkness adaptation with the other will probably not be as far apart as we have found for red and blue in Table 4. Here again thresholds were made as promptly as possible first with one eye and then with the other for a period of 18 minutes, after removing the red-opaque goggles. In place of giving the results in terms of successive 2-min. intervals, they are presented in 6-min. periods. We have as a rule from 3 to 6 threshold values for each eye for each subject and for each 6-min. period. By taking the means for these small groups of thresholds we improve the regularity and dependability of our compared data.¹¹ In Table 5 individual mean thresholds for paired replicates are presented. These are the results from wearing the red goggle over the left eye and an opaque screen over the right eye for 25 min. in an illumination of about 8 ml.¹² In the first 6-min. period, I, left-hand portion of Table 5, following removal of the goggles, we find that 13 of the 16 subjects show a lower threshold for the eye that was covered by the opaque screen than for the one covered by the red goggle. The means are 2.657 as compared with 2.810 log. $\mu\text{L.}$, mean difference -0.153, $P = 0.01$. In period II darkness adaptation, that is, the opaque goggle, again gives the lower mean but the mean difference, -0.057, is small and does not measure up to our criterion for significance. For period III the two means fall very close together and the difference, which is small, happens to turn in the other direction, +0.013, $P = 0.05$.

Table 6

Paired replicates for comparative monocular dark adaptation thresholds after wearing a red goggle over the right eye and an opaque screen over the left eye for 30 minutes. Values given in log. micro-micro-lamberts.*

Cases	I			II			III		
	Time: 1-6 min.			Time: 7-12 min.			Time: 13-18 min.		
	Red	Opaque	Diff.	Red	Opaque	Diff.	Red	Opaque	Diff.
S. R.	2.53	2.15	-0.35	2.42	2.19	-0.23	2.21	2.22	+0.01
F. B.	2.71	2.74	+0.03	2.77	2.79	+0.02	2.75	2.79	+0.04
L. T.	2.72	2.52	-0.20	2.56	2.37	-0.19	2.43	2.42	-0.01
H. M.	3.17	2.70	-0.47	3.02	3.32	+0.30	3.01	2.71	-0.30
B. W.	2.56	2.44	-0.12	2.60	2.59	-0.01	2.53	2.44	-0.09
H. C.	2.83	2.74	-0.09	2.61	2.98	+0.37	2.54	2.58	+0.04
E. G.	2.61	2.48	-0.13	2.65	2.53	-0.12	2.49	2.46	-0.03
A. R.	2.56	2.34	-0.22	2.44	2.25	-0.19	2.45	2.19	-0.26
C. R.	2.68	2.36	-0.32	2.62	2.74	+0.12	2.77	2.57	-0.20
F. T.	2.68	2.61	-0.07	2.43	2.29	-0.14	2.28	2.25	-0.03
A. K.	3.53	3.20	-0.33	3.09	2.86	-0.23	3.14	2.94	-0.20
E. W.	2.63	2.72	+0.09	2.52	2.69	+0.17	2.50	2.90	+0.40
F. M.	2.74	2.68	-0.06	2.74	2.50	-0.24	2.78	2.55	-0.23
J. S.	2.69	2.50	-0.19	2.64	2.58	-0.06	2.63	2.61	-0.02
D. G.	3.83	3.63	-0.20	3.14	3.25	+0.11	3.09	2.95	-0.14
M. H.	3.24	2.99	-0.25	2.98	2.66	-0.32	----	----	----
N = 16 Ms,	2.857	2.675	+0.182	2.702	2.662	+0.040	2.640	2.572	+0.068
			P = 0.01			P = 0.05			P = 0.05

*Measurements taken with the aid of the Hecht-Schlaer adaptometer No. 8 using Corning violet filter No. 5113, 3° test field centered 7° below a small red fixation point. The adaptation goggles featured a red Corning No. 2403 disc for one eye and an opaque cardboard disc for the other. The eyes were tested alternately as rapidly as possible after the goggles were removed. The subjects were pre-adapted to 693 ml. for 3 min.

The same subjects repeated the experiment on another day except that they wore the red goggle over the right eye and the opaque screen over the left eye. The same routine applied to the second experiment and the results are presented in Table 6. We find means for period I that closely parallel those in Table 5. The difference in favor of dark adaptation with the opaque screen is a little larger, -0.182 , $P = 0.01$, as compared to -0.153 . The mean difference is smaller for period II in Table 6 being only -0.040 , $P = 0.05$. In the final period, 13-18 minutes, in Table 6, the mean difference is in the general direction represented by the rest of the table but too small to be significant.

If we compare Tables 5 and 6, column for column, examining the mean differences we note that the results for the left eye are slightly lower than those for the right eye, but no one of these 6 differences is found to be significant at the level $P = 0.05$. On the other hand, when within Table 5 we compare the red mean for I with the red mean for II, respectively 2.810 and 2.594, the mean difference, 0.216, is significant, $P = 0.01$. Similarly, in Table 5, the mean for red thresholds in periods II and III, 2.594 and 2.491, show a difference of -0.103 . This also proves significant, $P = 0.01$. And the same is of course the case when we compare I and III where the difference is -0.319 , $P = 0.01$. A comparison of this same sort for the red thresholds for Table 6 gives substantially the same findings: I and II, difference -0.155 , $P = 0.01$; II and III, a small difference, -0.062 , $P = 0.05$; and I and III, difference of -0.217 log. $\mu\text{L.}$, $P = 0.01$. The story told by this comparison is that the eyes when pre-adapted to red light for 30-min. under the conditions used were not thereby completely dark-adapted but during the following 18 minutes exhibited a considerable increase in dark adaptation. On the other hand, if we examine the successive values in Tables 5 and 6, recorded under columns designated Opaque, analysis for Table 5 shows the following: I and II, difference -0.120 , $P = 0.02$; II and III, difference -0.033 , $P = 0.05$; and I and III, difference -0.153 , $P = 0.015$. The difference of -0.153 , is moderately large but only one-half as large as the difference in the same table between I and III for red thresholds. In Table 6 the three similar comparisons all yield differences that are small, none reaching significance at the 5 per cent level.

If we submit the data of Table 4 to a similar analysis as applied to Tables 5 and 6, we find a dependable difference, -0.184 , $P = 0.02$, for the comparison of I and II (red), that is, 2.718 and 2.534. Nowhere else in Table 4, though, do two adjoining periods provide means with a difference that is significant at the 5 per cent level. If we compare periods I and III, II and IV, and III and V, etc., we get a significance exceeding $P = 0.05$ for I and III, but nowhere else in the table. A comparison of periods I and IV, II and V, and III and VI all reveal differences dependable at $P = 0.01$, however IV and VII, V and VIII, and VI and IX all fail to reach criterion of $P = 0.05$ level.

From our experiments on simultaneous differential monocular adaptation reported in Tables 4, 5, and 6 we appear to have dependable evidence that 30 minutes' use of a red goggle achieves a large degree of dark adaptation, but not as great a degree as to have had the eye completely shielded from light. Furthermore, complete shielding of the eye from light, for 30 minutes, produces a state of dark adaptation that, according to our thresholds measurements, increases barely significantly in the next 18 minutes, while the dark adaptation produced during exposure to red light, (cut off at 620 m μ and photopic transmission of 3.5%) for 30 minutes is shown to increase significantly in the next 18 minutes, while threshold measurements are made in dark surrounds.

Discussion

The practical usefulness of red light as a means of securing and retaining dark adaptation of sufficiently low level for effective night vision on outdoor missions is not under discussion here. Laboratory experimentation and especially the wide experience of the military services in recent years have proven the success and importance of this visual technique. But, is it possible that red light provides a more effective means for securing dark

adaptation than that of complete darkness? This is the question which Lt. McLaughlin's recently published results appear to answer in the affirmative.

There seems little to criticize in McLaughlin's experimental design or in the conditions and procedures employed. The design is rather similar to that used in the (British) Admiralty Research Laboratories, 1941, which reported lower thresholds following the use of red light for a portion of the adaptation period than after an all-dark adaptation procedure. McLaughlin's design is also favorable in that he took the two sets of results for a subject on the same day using the red light procedure first with some subjects and second with others. The experiments with red goggles and dark adaptation done at Yale in 1941 and 1942 unfortunately did not employ as good experimental design. The data secured at that time are presented in this paper in Tables 1, 2, and 3. The means, differences and probability tests turn out favorable to the red light as compared to the darkness procedure. In our earlier paper it was suggested that the lower thresholds secured by means of the red goggles might result from poorer motivation, retinal fatigue or from general fatigue. "The experiments carried out with the goggles made somewhat less demand on the subjects than when serving for the full adaptation curve. Also, the portion of retina tested in the experiments was subjected to more low-level stimulation for obtaining the thresholds represented in the complete curve than in the goggle tests."¹³ This still seems to us a possibility and especially so in the light of our results from monocular studies. The effects of monotony and boredom on sensory and perceptual thresholds are difficult to appraise. Possibly some such method as devised by Kennedy and Travis for the automatic registration of "alertness" through muscle action potentials would be useful here as they found it with records of continuous tracking performance.¹⁴

In the monocular experimentation we have found that although the red light as a means of promoting dark adaptation seems to do well, it does not yield flash thresholds as low as those made under similar intervals of time after adaptation to darkness. It has long been known that the two eyes can be adapted independently of each other and this fact has been of wide military usefulness.¹⁵ Our group of 16 practiced subjects, each serving in a matched pair of tests, examined by a well-trained technician, supply evidence that adaptation to red light in one eye does not advance the process of dark adaptation to as low level in the same amount of time as is achieved from adapting the other eye to the absence of light. The question of whether one condition was more stimulating to the subjects than the other seems hardly to apply under this situation of simultaneous, differential monocular adaptation. In each experimental session with each subject one or the other of the subject's eyes was stimulated by red light. It seems unnecessary to assume that in the period of measurement the subject would take a different attitude or be more alert when one eye was under test than with the testing of the other eye. Monocular adaptation seems to the writer a favorable method for use in the study of this problem on a relatively small group of practiced subjects. And since our duplicate sets of results, for 16 subjects, show statistically reliable differences in favor of darkness in comparison to red light, especially in the first few minutes after removing the goggles, the theoretical possibilities for a facilitative effect of red light on dark adaptation for the time being seem not to press for discussion.

Summary

Some studies of 1941-1942 indicated that adaptation under red light was faster than in darkness. A recent (May 26, 1952) research report originating from the Naval Air Station at Pensacola seems to show a facilitative effect of red light on dark adaptation and has renewed interest in this problem. Some of the earlier data purporting to show this effect, additional material previously unpublished, and also new studies made at Yale by the method of simultaneous differential monocular adaptation are here presented and discussed. Adaptation goggles were used for 25 min. under illumination of 8 ml. The filter over one eye was a glass disc made of Corning No. 2403, deep red, 3.5% photopic transmission, over the other eye an opaque cardboard disc which excluded all light. Dark adaptation thresholds

(Hecht-Schlaer adaptometer) violet light (Corning 5113), measured alternately on the two eyes showed for 16 college student subjects lower values, i.e., increased light sensitiveness for the eyes adapted in darkness. In the period 6 min. after removing the goggles the mean threshold difference between results for red and opaque procedures in the first test was $-0.153 \log. \mu\text{L.}$, $P = 0.01$; in the second test with the goggles reversed on the two eyes the mean difference favoring the opaque side was $-0.182 \log. \mu\text{L.}$, $P = 0.01$. The earlier and later results are not easily harmonized. The author argues in favor of the monocular method as an appropriate one for the study of this problem.

Notes and References

1. D. Y. Solandt, "Progress report of research on airplane instrument board lighting." Proc. Canada, NRCC. Assoc. Committee On Aviation Med. Research. October 4, 1940. 2 pp.;
and H. K. Hartline, R. McDonald and G. A. Millikan, "Tests on the impairment of pilots' night vision due to illuminated instrument panels. Comparison of red and green illumination." USA-NRC Committee on Aviation Medicine, Report No. 4, March 1941. 3 pp. mimeo.
2. This Yale research and development had no military or governmental contract supporting it. We regarded the results as worthy of confidential status and proceeded accordingly making no publication at the time. While in England in May 1942 on a mission for OSRD the writer first learned that the U.S. Navy Dept. had issued an unclassified report describing red dark adaptation goggles, and the technique of their use. See "The use of the eyes at night," by Comdr. Eric Liljencrantz, Comdr. Clifford A. Swanson, and Lt. Comdr. Leon D. Carson, Night Vision Board, Navy Dept. Bureau of Med. and Surg. Washington, D.C. April 15, 1942, pp. 1-23, 6 Figs. mimeographed; published also in U.S. Naval Institute Proc. June 1942.
3. W. R. Miles, "Red goggles for producing dark adaptation." Federation Proceedings, Vol. 2, No. 2, June, 1943, pp. 109-115, part of "Symposium on the special senses in relation to military problems," Hallowell Davis, Chairman, pp. 107-129.
4. Admiralty Research Laboratory (Great Britain) "Dark adaptation following exposure to red, orange and white light for different times and at different intensities." ARL/N6/0.360, 19 November 1942, 4 pages, 4 tables and 10 figures.
5. "A facilitative effect of red light on dark adaptation." Report by Lt. Samuel C. McLaughlin, Jr., MSC, USN., Research Report, U.S. Naval School of Aviation Medicine, May 26, 1952, 7 pages and 2 tables, Unclassified.
6. The threshold determinations reported here for 1941 and 1942 were all taken by the same skilled assistant, Mrs. Marion R. Chapanis, whose cooperation I gratefully acknowledge.
7. See note No. 3 for full reference. The author still has some spare reprints of this article. Interested readers are welcome to them so long as the supply lasts.
8. Admiralty Research Laboratory (Great Britain) "Effect of red, orange and white light on rates of dark adaptation." ARL/N6/0.360, 19 October, 1942. 4 pages, 8 tables and 3 figures.
9. The threshold determinations reported here for 1943 were all taken on the Hecht-Schlaer Adaptometer No. 8 by Mrs. Eleanore F. Hubbard who had 3 mos. training and experience with the adaptometer in other experiments before beginning this reported series on monocular adaptation. Mrs. Hubbard's assistance is gratefully acknowledged.

10. W. M. Rowland and L. L. Sloan, "The relative merits of red and white light of low intensity for adapting the eye to darkness," J. Opt. Soc. Am. 34, 601-604, October, 1944; S. Hecht and Yun Hsia, "Dark adaptation following light adaptation to red and white lights," J. Opt. Soc. Am. 35, 261-267, April, 1945; and Z. J. Schoen and F. L. Dimmick, "Relative efficiency of goggles for dark adaptation," U.S. Naval Med. Lab., U.S. Naval Submarine Base, New London, Conn. April 9, 1948, NM 003 024(X-757 (Av-387-k)) Progress Report No. 1.
11. About 7% of the threshold values entered in Tables 5 and 6 are based on one or two measurements made in a 6-min. period.
12. This represents the time spent in the light adaptation room, an additional 5 min. were required before the light in the adaptometer room was turned off and the goggles were removed.
13. See reference No. 3, page 113.
14. J. L. Kennedy and R. C. Travis, "Prediction and control of alertness. II. Continuous tracking," J. comp. physiol. Psychol., 41, 203-210, June 1948.
15. A. Chapanis, "How We See: A summary of Basic Principles," pp. 3-60, (See especially pp. 20-22), Chapter 1, in Part I, "General Visual Problems" in "Human Factors in Undersea Warfare," Prepared by the Panel On Psychology and Physiology, Committee on Undersea Warfare, National Research Council, Washington, D.C. Pp. x + 541, 1949.

AN EVALUATION OF PROBLEMS OF CHART
READING UNDER RED ILLUMINATION

Prepared by Alphonse Chapanis

PREFACE

The present report was prepared by Dr. Alphonse Chapanis, of The Johns Hopkins University, to summarize the status of problems encountered in chart* reading under red illumination.

Material for the report was obtained primarily from a conference held on 30 September 1952 at the Naval Medical Research Laboratory, U.S. Submarine Base, New London, Connecticut. The following persons attended the conference:

Group Captain Clement McCulloch, RCAF
Wing Commander A.G. Watson, RCAF
Mr. W. E. Knowles Middleton, National Research Council of Canada
Lieutenant Colonel Walter F. Grether, USAF
Captain Leroy Pigg, USAF
Captain Charles Seeger, USAF
Lieutenant Commander Dean Farnsworth, USN
Lieutenant Samuel C. McLaughlin, USN
Dr. John Lazo, USN
Mr. Peter Bricker, The Johns Hopkins University
Dr. Mason Crook, Tufts College
Mr. Richard T. Mitchell, Harvard University
Dr. John H. Taylor, Vision Committee Secretariat,
University of Michigan
Dr. Alphonse Chapanis, The Johns Hopkins University, Chairman

Following the conference, Dr. Chapanis prepared a first draft of a report of the conference for review and criticism by those who attended the conference and by those who had been invited but were not able to attend. The present report summarizes the consensus of the New London conference and includes such additional notes, discussion, and references as were supplied by various persons following the circulation of the first draft of the report of the conference. To assimilate the new material into the report and to complete the report within a reasonable time, it was necessary for Dr. Chapanis to make certain changes which have not been reviewed by the group as a whole. He accepts responsibility for such inaccuracies as may still exist in the present report and for any statements which do not reflect the opinion of the group.

*This report will follow the accepted Navy and Air Force practice of calling aeronautical maps "charts."

The present report will take the form of a description of the discussion of the New London conference, with additional material interpolated from time to time.

The conference began with a review of the origin of the request that the Vision Committee consider the status of problems of chart reading under red illumination. Mr. Middleton informed the group that the conference had its origin in a request made to him by the Surveyor General of Canada for advice concerning charts suitable for use in daylight and at night under red illumination. Mr. Middleton felt that there were several distinct questions involved, and that they could be classified into three major groups:

1. Operational requirements. Red cockpit lighting is used to preserve the dark adaptation of pilots. But an important question which no one seems to have answered is this: How much dark adaptation does the pilot need to perform his tasks? This is a question of operational requirements which can only be answered by a study of operational situations. For example, it might be that most pilots fly by radar, so that direct vision outside the aircraft is little needed and of minor importance. This is the sort of question, however, which the group is in no position to answer.

2. Visual requirements. It is generally agreed that pilots need to read charts, and to read charts they need light. If there is a considerable amount of light present, it may, even if it is red, affect dark adaptation. Thus, it is necessary to ask: (a) How much red light is needed to read charts of different kinds? And, (b) How much will these amounts of light reduce dark adaptation?

3. Technical requirements. The technical requirements of chart construction interact to some extent with the questions raised in the two preceding paragraphs. There is, first, the question: Is it really necessary to have maps suitable for both day and night use? It may be, for example, that charts used at night should be simplified to present less information than appears on charts used in daylight. Other members of the group raised the question whether the hypsometric scale is necessary, or even worth the cost of printing, for night flying. An alternative to the hypsometric scale is the use of spot elevations--an alternative which the U. S. Air Force's representatives favored. In any case, there are some important questions regarding the specification of colors to be used for charts particularly if they are to be used under red illumination. To illustrate the last-named problem, Mr. Middleton exhibited a set of 16 colors used on Canadian aeronautical charts. When these 16 colors were viewed under red illumination, the order of their luminances was completely changed from that under daylight illumination. In addition, many colors which were easily discriminable under daylight illumination became indistinguishable under red illumination.

Lt. Col. Grether stated that the Air Force was most concerned with the questions raised under the heading of the operational requirements. He felt that most people seem to have gone overboard in recommending extreme dark adaptation for pilots, and he cited recent operational data which showed not only that pilots needed less dark adaptation than is commonly supposed, but also that there is little loss in dark adaptation due to normal cockpit lighting. He indicated the need for considering how much visibility is impaired by reflections from windscreens, dirt and dust on the windscreens, and so on, since it is possible that night visibility might be limited by factors such as these rather than by dark adaptation. Finally, he cited the results of recent experiments (19) comparing the effects of low color-temperature white light and red light on dark adaptation. Although the

former was worse, it was not, he felt, appreciably so.

Group Captain McCulloch felt that the problems of the RCAF were special because of the role assigned to the RCAF in the over-all continental defense plan. The RCAF has essentially only two types of aircraft: transport, and fighter (at the present time, the CF100 and F-86). In the former aircraft, dark adaptation may be of no great concern, since there is a navigator in the aircraft who presumably would be primarily concerned with chart reading, and for whom loss of dark adaptation would have no serious effects. It is important to note, however, that the navigator may also have external visual tasks, such as pilotage and target identification, but the frequency or importance of such tasks is not known. For pilots of fighter aircraft, dark adaptation is not important since direct vision is of trivial consequence in air-to-air combat at the speeds these aircraft fly. Radar is used to vector the aircraft out, position the aircraft for offensive passes, and vector the aircraft home.

Group Captain McCulloch also exhibited an RAF chart* (see reference (28)) which was so designed that under red illumination certain lines and symbols disappeared. The disappearing symbols were those not important to night flying (for example, small country roads) because they could not be seen by the pilot anyway. The group agreed that this chart appears to have a great many interesting and carefully planned characteristics.

Lieutenant Commander Farnsworth presented the group with preprints of a recent report (11) which summarized the results of a number of experiments on visual performance at various brightness levels. Although the criteria and visual tasks of these experiments were diverse--reading dials, doing problems in addition, reading letters, and so on--they are consistent in showing that there is little appreciable loss in visual performance until luminance levels decrease to 0.05 foot-lamberts or less. The group felt that Commander Farnsworth's summary might well provide us with an upper limit of illumination necessary for chart reading. Dr. Lazo added that on the basis of work at the Naval Air Materiel Center (2), they were recommending two fixed floodlighting levels for use with transilluminated panels. The lower value is 0.05 foot candles measured as an average over the instrument and console panels. This amount of floodlighting is sufficient to provide general orientation in the cockpit, reduce excessively high contrast, and highlight knobs and controls. Further, with this floodlighting level, the pilot may select brightnesses for transilluminated markings and letters from approximately 0.02 footlamberts (the lowest intensity setting) to the maximum obtainable. The higher recommended floodlighting level is 0.2 foot candles. It is designed to provide the pilot with higher illumination levels in case he needs better cockpit orientation, or in case the transillumination system fails.

Upon further study of these data, however, Dr. Crook commented that the summary of visual performance presented in Farnsworth's report might be misleading if applied to the chart-reading task without some qualification. The tasks reviewed by Farnsworth were mainly the reading of dial and console markings, in some cases transilluminated, and characteristically somewhat larger than small printed type. The Rock study, cited by Farnsworth, did use printed type, the conditions being such as to make it equivalent in visual angle to 10-point type at 14 inches. On aeronautical charts, however, there is a considerable amount of 8- and 6-point type at the present time. A report by Crook et al. (9) from the

*R.A.F. 1:500,000, GSGS 4072. Sheet NW 53/6-1/2. First Edition--GSGS. Compiled and drawn by Ordnance Survey. Published by War Office, 1951.

Tufts laboratory shows data for 10-, 8-, and 6-point type as a function of illumination. The results for 10-point type were very similar to those of Rock, with little improvement above about 0.05 footlamberts, but the corresponding level for 6-point type was in the neighborhood of 0.15 footlamberts. Legibility is further impaired on charts, as they are now printed, by such factors as poor contrast (see Crook et al. (8)) and crowding. This puts a further premium on additional illumination. Everything considered, Dr. Crook feels that there is quite a gap between what can be read at 0.05 footlamberts and what people are expected to read on present-day charts.

Dr. Chapanis mentioned a report dated September 17, 1942 ((22); see also reference (28)) which summarized a conference to which the services and a number of government agencies had sent representatives. At that conference the (at that time) Maps and Charts Division of the Directorate of Photography had presented participants with copies of charts which were not only designed for viewing under ultra-violet light but also were tonal-keyed for red illumination. The Aero Medical Laboratory had undertaken a few quick appraisal tests of these charts, the results of which are reported in (3) and (22). Briefly, the results seemed to indicate that the charts were readable under red illumination, and that when the charts were so used they raised the dark adaptation threshold by only 0.3 log units--a loss which was very nearly recovered one minute later. Dr. Chapanis stated that, according to his recollection, these charts were highly satisfactory, and he inquired whether anything further had ever been done with them. Representatives of the Air Force seemed to feel that the development of these charts had apparently been dropped in 1943 and the reports buried. Dr. Crook stated, however, that he was attempting to recover this old work. He has located some of the original 1942 charts, is studying them, and continuing their development. He has not been able to determine whether the experimental charts in question ever got into use in the field.

Dr. Crook summarized the nature of the Tufts contracts with the Air Force. As part of these contracts, Dr. Crook's research team has made colorimetric analyses of the colors now used on the World Aeronautical Charts and is attempting to formulate tentative specifications for colors suitable for use under red illumination. They are going ahead on the basis of three assumptions: (1) colors will be used, (2) that 11 colors are desirable, (3) that the C-4 cockpit lamp will be used as the primary source of red illumination. Dr. Crook also suggested the possibility of printing maps on two sides--one for day use, the other for night use.

Dr. Crook then spent some time discussing the complexity of the technical problems involved in designing charts of this sort. These charts need to be designed as systems, because each of the several factors interacts with the others. For example, the interrelationships of all the colors need to be considered at once. Changing the present hypsometric tints to make them distinguishable under red illumination might mean the re-specification of other colors to make them distinguishable from the hypsometric colors. In addition, Dr. Crook emphasized the highly important questions of economy and feasibility of printing. At the present time, three or four runs through printing presses are required to print the 11 colors now used on Air Force charts. This is a relatively economical procedure, and it is necessary to guard against any future group of colors being so selected that they would be difficult or costly to produce with present-day printing inks and techniques.

Finally, Dr. Crook called attention to some research which had been done by Dunlap and Associates, Inc., on the design of charts for high-speed, high-altitude flying (6, 7, 10, 14, 15, 16, 24). As a consequence of this research, the Dunlap group has been able to suggest ways of simplifying aeronautical charts and,

coincidentally, of improving their legibility under night lighting. Among other things, they compared the readability of several aeronautical charts under low level red illumination (20). Using the facilities of Tufts College, they showed that the Navy experimental jet navigation chart, type XDA,* can be read more accurately and more quickly than the USAF XJN chart** on all items except radio beacon and range information. This superiority may be attributed to the use of greater contrast for printed material, larger size of type, the selection of colors for legibility under red illumination, and a pictorial type of symbol. As illustrations of the last item, mountain elevations are portrayed by shadowing, rather than by contour lines, and airports are portrayed by realistic runway patterns. Dr. Crook also exhibited samples of the XDA and XJN charts.

Mr. Mitchell described a bibliographic project undertaken for the Vision Committee by Dr. William S. Verplanck of Harvard University. This work is concerned with a survey and critical evaluation of the literature dealing with the effects of conditions of prior light adaptation on subsequent dark adaptation. At the present time, a bibliography of some 300 items has been collected, but neither Dr. Verplanck nor Mr. Mitchell will be able to abstract this material as originally planned. In general, the bibliography deals with studies showing the effects of the duration, intensity, and color of the light used for light adaptation on subsequent dark adaptation. Presumably, therefore, the answers to some of the questions about the visual requirements of the chart reading task might be contained in this bibliography. However, the consensus of the group was that complete answers would not be found in the literature for three reasons: (a) Most laboratory studies on the effects of pre-adaptation upon subsequent dark-adaptation have used unrealistic pre-adaptation intensities. In general, these studies have been concerned with theoretical questions about the visual process and so have used intensities of pre-adaptation much higher than would be encountered in cockpits. (b) Most laboratory tests have been concerned with the course of dark adaptation following various levels of pre-adaptation, and very few have been concerned with the more practical measurement of the instantaneous threshold following various pre-adaptation levels. (c) Most laboratory studies have used tests of dark adaptation, i.e., simple light perception, and very few have used more realistic visual acuity targets, or tests of form perception, at near threshold levels.

In correspondence following the New London conference, Dr. Crook indicated that the Tufts College Institute for Applied Experimental Psychology has a contract with Griffiss Air Force Base, Rome, New York (Contract No. AF30(602)-199), for research under the general heading, "Determination of the pre-exposure tolerance of the dark-adapted eye." The Tufts project director on this contract is Dr. Joseph W. Wulfeck. The times and intensities of pre-exposure to be investigated are such as might characterize short periods of chart reading while piloting an aircraft, but because of the area of interest at Griffiss Air Force Base, the emphasis will be on white light rather than red light. Work during the first quarter is being directed largely toward an investigation of the literature. In this connection Dr. Verplanck has made his bibliography available to Tufts.

*Jet Navigation Chart (XDA 9 3-1), 1st experimental edition, published by the USAF Aeronautical Chart and Information Service, Washington 25, D. C., March 1951. (See also reference (5).)

**USAF Jet Navigation Chart (XJN 9-3), prepared for use at night under white, ultraviolet, red and amber lights, 4th experimental edition, published by the Aeronautical Chart Service, U. S. Air Force, Washington, D. C. January 1951.

Under the Tufts contract, it is planned to submit to Griffiss Air Force Base the following:

- a. A fairly inclusive bibliography of titles on dark adaptation.
- b. An annotated bibliography of research reports directly related to dark adaptation as a function of duration and intensity of pre-exposure.
- c. As an introductory part of the first report of experimental results, a critical review of the material covered in b above.

As things stand at present, there is no provision for an adequate coverage of the wavelength variable in relation to dark adaptation such as would have been done by Dr. Verplanck and Mr. Mitchell. It is possible that attention can be given to the wavelength variable in the reports now being prepared at Tufts, as much of that material is available, but a thorough job in that direction would be beyond the scope of the present contract.

To return to the proceedings of the New London conference, Lieutenant McLaughlin questioned whether enough research has been done on the effects of red illumination, with varying cut-offs in the red end of the spectrum, on subsequent dark adaptation. He also cited some recent research which shows a facilitative effect of red illumination on dark adaptation (18). Lieutenant Commander Farnsworth commented that, whatever the theoretical interest or importance of such data, we must not lose sight of practical limitations. The cost in terms of increased power requirements to produce deep red light, for example, may make slight gains in dark adaptation prohibitively expensive.

Various other members of the group participated in the discussion of these and related points. On the basis of this discussion, the group made decisions as follows:

1. The group agreed that problems of reading charts under red illumination exist, that these problems are complex, and that they are important.

2. The group agreed that there is no good body of reliable information we can use to answer the question: How much dark adaptation does the pilot need to perform his tasks effectively and safely? Various needs for dark adaptation in operational situations were listed--for example, air-to-air night combat, dropping parachute troops in enemy country at night, night attacks on enemy ground targets, avoidance of air collisions at night, night reconnaissance, and helicopter landings in enemy territory--but the evaluation of these at the moment is largely controversial and a matter of diverse opinions. The group agreed that this information is needed and

RECOMMENDED THAT OPERATIONAL REQUIREMENTS FOR DARK ADAPTATION IN MILITARY AND CIVIL AVIATION BE STUDIED. AS PART OF THIS STUDY, THE GROUP RECOMMENDED THAT SUMMARY JOB ANALYSES BE PREPARED FOR ALL AIR CREW MEMBERS ABOARD VARIOUS TYPES OF AIRCRAFT TO FIND OUT FOR WHICH CREW MEMBERS COMPLETE DARK ADAPTATION IS ESSENTIAL, FOR WHICH ONES SOME DARK ADAPTATION IS NECESSARY, AND FOR WHICH ONES NO DARK ADAPTATION REQUIREMENT EXISTS. FINALLY, THE GROUP RECOMMENDED THAT RESEARCH BE INITIATED ON THE COLLATERAL PROBLEMS OF (1) THE

IMPAIRMENT OF VISIBILITY OUTSIDE THE AIRCRAFT CAUSED BY DIRTY WINDSHIELDS, REFLECTIONS FROM WINDSCREENS, AND SO ON, AND (2) THE RELATION BETWEEN DARK ADAPTATION AS USUALLY MEASURED AND THE DETECTION OF LOW CONTRAST TARGETS UNDER SERVICE CONDITIONS, ESPECIALLY AT HIGH SPEEDS.

3. The group agreed that the formulation of specifications concerning the amount of light necessary for reading charts, and the answer to the subsidiary question of the deleterious effects of this amount of light on dark adaptation, depends on answers which would come from the operational study recommended above. There was agreement, however, that a considerable amount of information is available on the effects of the quality of light and the amount of light on the instantaneous threshold and subsequent dark adaptation. This information is scattered and the group

RECOMMENDED THAT PRIORITY BE GIVEN TO THE COMPILATION OF A BIBLIOGRAPHY OF LITERATURE, AND A CRITICAL EVALUATION OF THIS LITERATURE, TO SEE WHAT IS KNOWN AND WHAT IS NOT KNOWN ABOUT THE EFFECTS OF PRIOR LIGHT ADAPTATION UPON THE INSTANTANEOUS THRESHOLD AND SUBSEQUENT DARK ADAPTATION.

As the most expedient way of implementing this recommendation, efforts should be made to provide additional support to Tufts College so that their survey of the literature can be extended to include more material on (1) wavelength as it relates to subsequent dark adaptation, and (2) the effects of prior adaptation conditions on the instantaneous threshold and the detection of low-contrast targets. If such a survey should disclose gaps in our knowledge, research should be undertaken to fill them.

4. The group agreed that there needs to be a careful re-examination of the question: What information is needed on a chart for flying in daylight and at night? Although the committee felt that it was in no position to make further recommendations regarding this aspect of the problem, it called attention to:

- a. the unique and desirable features of the RAF chart discussed above, and
- b. the possibility that a combination of red and ultra-violet light might be used for special purpose applications, for example, for locating emergency landing fields which might be printed on charts in fluorescent inks.

5. The group agreed that the design of charts for day and night use is a complex one involving questions of economy and the interrelationships of all the colors on the charts. The group took note of the RAF charts and the AF charts printed in 1942. It agreed that these are good starting points for further work on these problems. Finally, the group noted that the entire system of colors is currently being investigated by Dr. Mason Crook. The group endorsed Dr. Crook's work and

RECOMMENDED THAT DR. CROOK BE ENCOURAGED TO CONTINUE AND COMPLETE HIS WORK.

REFERENCES

It is the chairman's opinion that one of the most important outcomes of the New London conference and the correspondence which followed it was the compilation of a substantial bibliography of reports relating to the general problem of chart reading under red illumination. As is so commonly the case with topics of military interest, it turns out that there is a sizable number of reports on this subject, but they have been issued by a great variety of organizations with very restricted circulation. It would have been difficult for any single person to have collected this list of reports; it required rather the special knowledges and sources of information represented by the various persons who participated in the conference.

The list of references which follows is not necessarily exhaustive. Some of the references were supplied by participants in the 30 September conference to document points of discussion made at that time. The majority of the references, however, were sent in following the distribution of the first draft of this report. A number of the references were discovered by Dr. Chapanis, who also attempted to examine and evaluate each one from the standpoint of its relevance to the subject matter of this report. He was able to see scarcely more than half of them, however, and so unfortunately is not able to vouch for the accuracy of citations or the relevance of every item. Despite these shortcomings, the bibliography which follows should provide a valuable source of information as a starting point for further work on this problem.

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Discussion:

- Dr. Hulburt asked about the possibility of using one eye for tasks involving dark adaptation and the other eye for tasks involving light adaptation.
- Dr. Chapanis agreed that such a technique is a possible solution to the dark adaptation problem. He went on to say that the Air Force is of the opinion that the need for dark adaptation has been greatly overemphasized and that an operational study of the requirements for dark adaptation would be profitable.
- Col. Byrnes asked whether the design of aeronautical charts depends upon the prior establishment of the level of red light permissible for the maintenance of dark adaptation.
- Dr. Chapanis replied that the type of detail included in the aeronautical chart will depend upon the level of illumination under which it is used. It was Dr. Chapanis' opinion, therefore, that all parts of the study would have to proceed simultaneously, since, in effect, one has to know the requirements for detail to be read on the chart before establishing illumination levels and yet one must also know the amount of dark adaptation required in order to establish illumination levels.
- Col. Grether reminded the group that the use of low color temperature white light might be acceptable. Such a possibility permits greater use of colors in the aeronautical chart than the use of red light.

The following recommendations were approved by the Vision Committee:

RECOMMENDED THAT OPERATIONAL REQUIREMENTS FOR DARK ADAPTATION IN MILITARY AND CIVIL AVIATION BE STUDIED. AS PART OF THIS STUDY, THE GROUP RECOMMENDED THAT SUMMARY JOB ANALYSES BE PREPARED FOR ALL AIR CREW MEMBERS ABOARD VARIOUS TYPES OF AIRCRAFT TO FIND OUT FOR WHICH CREW MEMBERS COMPLETE DARK ADAPTATION IS ESSENTIAL, FOR WHICH ONES SOME DARK ADAPTATION IS NECESSARY, AND FOR WHICH ONES NO DARK ADAPTATION REQUIREMENT EXISTS. FINALLY, THE GROUP RECOMMENDED THAT RESEARCH BE INITIATED ON THE COLLATERAL PROBLEMS OF (1) THE IMPAIRMENT OF VISIBILITY OUTSIDE THE AIRCRAFT CAUSED BY DIRTY WINDSHIELDS, REFLECTIONS FROM WINDSCREENS, AND SO ON, AND (2) THE RELATION BETWEEN DARK ADAPTATION AS USUALLY MEASURED AND THE DETECTION OF LOW CONTRAST TARGETS UNDER SERVICE CONDITIONS, ESPECIALLY AT HIGH SPEEDS.

RECOMMENDED THAT PRIORITY BE GIVEN TO THE COMPILATION OF A BIBLIOGRAPHY OF LITERATURE, AND A CRITICAL EVALUATION OF THIS LITERATURE, TO SEE WHAT IS KNOWN AND WHAT IS NOT KNOWN ABOUT THE EFFECTS OF PRIOR LIGHT ADAPTATION UPON THE INSTANTANEOUS THRESHOLD AND SUBSEQUENT DARK ADAPTATION.

RECOMMENDED THAT DR. CROOK BE ENCOURAGED TO CONTINUE AND COMPLETE HIS WORK.

CONSIDERATIONS IN THE CHOICE OF BRIGHTNESS LEVELS FOR RED LIGHTING

Dean Farnsworth

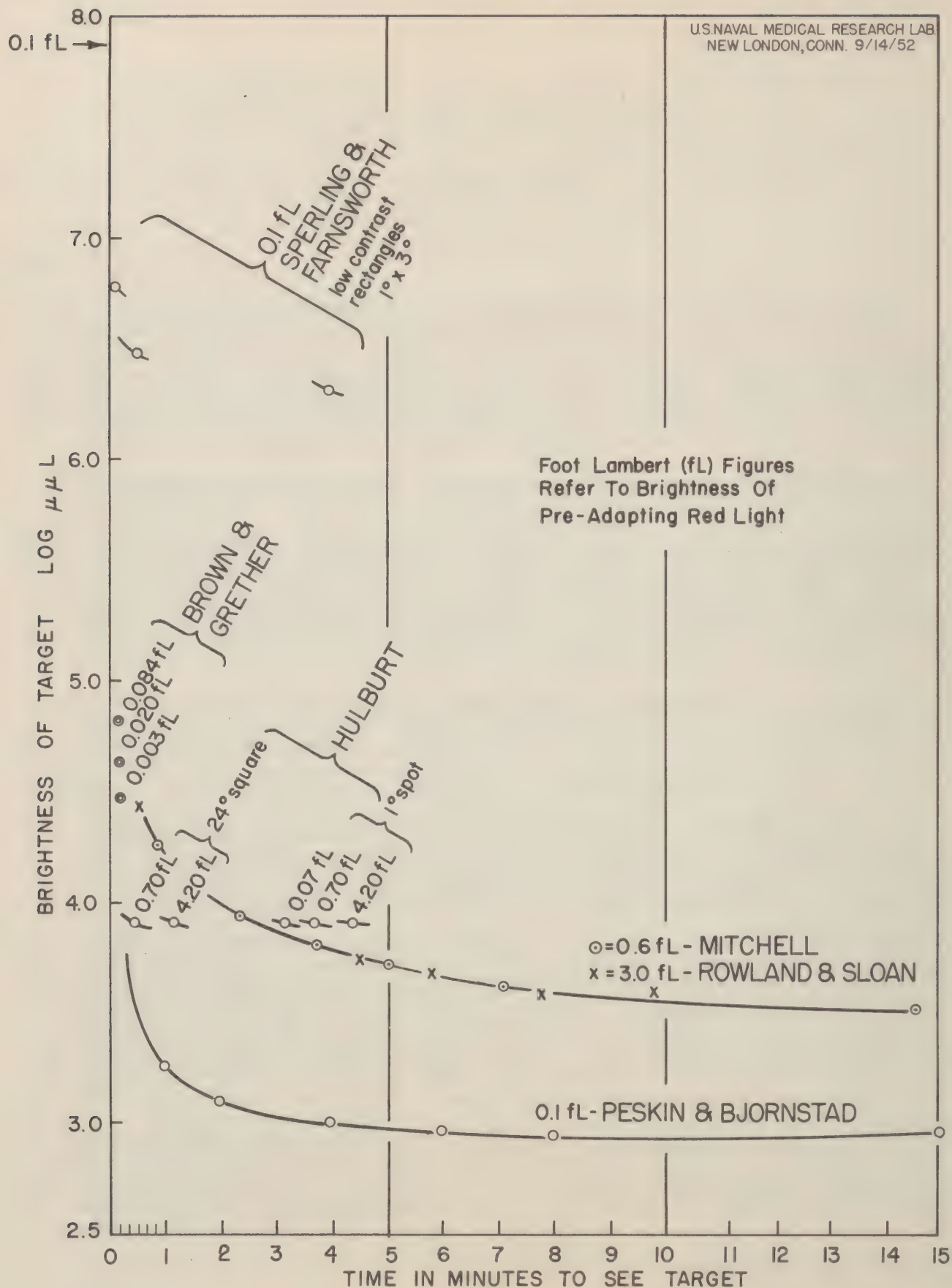
Naval Medical Research Laboratory
U.S. Naval Submarine Base

Our attempts to apply published laboratory data on dark adaptation to particular situations has been very unsatisfactory. Taking for example the specification of red lighting levels for submarines this paper (1) will show the process we went through in the course of attempting to determine brightness level requirements, (2) will present all of the data which appears to be at present available to those with similar problems in aviation, ground forces and surface vessels (in Figures 1 and 2) and, (3) will continue with remarks on the problem of making our laboratory research applicable to actual operating situations.

Lower limits of illumination - both white and red - must be safely above the minimum levels which permit easy and reliable performance of visual tasks. The conditions differ somewhat between the white and the red-lighted situation. Let us assume that white lighting should be adequate for normal living and working purposes while red lighting need be directed only to working efficiency. Then everything in the compartment should be easily visible under white light, but it is necessary only that the red light illuminate clearly those items required in the operation of the ship and in the safe and rapid movement of men about the ship. Therefore the lower limit of the white range is likely to be in the range between the upper and lower limits for red lighting.

Upper limits are somewhat determined by the selection of the lower limit for this reason: Since the whole boat - or even one bank of dials - cannot be uniformly lighted (or at least uniformly front-lighted), and since the determining visibility factor is the lowest brightness permitted for the darkest dial, then the brightest areas or dials will be those which result from illuminating the most-difficult-to-light areas or dials to the minimum specified level. Our readings taken on the latest lighting installations in submarines show that modern fixtures can usually be adjusted to give ranges of illumination as small as 1-10 on a specific working area. This indicates that the upper limit for red-lighted areas can be figured as about 10 times that of the lowest specifically lighted area, though difficult structural conditions may occasionally force us to accept considerably higher ratios.

Obviously, for ease of seeing, red illumination should be as high as is consistent with rapid subsequent adaptation. Let us first examine the effect of low preadapting brightnesses of red light on subsequent adaptation. Such psychophysical data are obtained with best stability and statistical reliability by methods of thresholds - usually reported in terms of the 50% limen. Therefore experiments which have used these and similar techniques will be first examined even though the data, as presented, are not often directly applicable to military operations. (There are times when approximate accuracy in the field is neither sufficient or safe, but it is of reasonable usefulness in night lookout, night fighter and periscope observation where first sightings may be preliminary to closer inspection.) Data from the few such available studies using preadaptations from 0.003 to 4.20 footlamberts are compared in Figure 1. Because of the great variety of experimental aims, methods, targets, and treatment of data in these studies it can be argued that it is misleading to present them in the same parameters. Nevertheless we have plotted selected data from the studies on one chart in order to aid in the visualization of the three generalizations which emerge.



From Figure 1 it appears that with low preadaptation with red light:

1. At relatively high night brightnesses, or for large targets, adaptation sufficient for detection is accomplished in seconds.

Compare the Sperling thresholds on the left with the threshold for slightly lower brightness on the right; compare Hulburt's data for 24° targets on left with that for 1° targets on the right.

2. More difficult targets (of lower brightness, or smaller) require a disproportionate increase in time for detection.

Note in the Sperling data that to achieve a decrease in threshold of less than .2 of a log unit requires 8 times as long a time; from the Hulburt data note that nearly 8 times as long is required to see a 1° target as a 24° target. In the typical adaptation curve by Peskin note that 5 log units of adaptation occurred in 1 minute as against $1/4$ log unit in the next 15 minutes.

3. Decrease of preadapting brightness by factors of from 10 to 100 does not greatly decrease the time to see a near-threshold target nor greatly reduce the immediate threshold.

Compare the effects of adaptation at .07 and .7fL for the 1° target by Hulburt: Only a minute and a quarter is shaved from four and a third minutes by reducing 4.2fL preadaptation to $1/60$ th of this value. For the Brown data note that a reduction in preadaptation of $1/28$ th, from 0.084 to 0.003fL, produces a change of less than 0.4 log μ L.; the same reduction in illumination levels on instrument panels produced no significant differences (which casts some doubt on the magnitude of even the above figures).

References for Figure 1

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We conclude from the above:

- 1) That great decreases must be made in the brightness of preadaptation lighting in order to achieve small decreases in postadaptation thresholds.
- 2) That levels of the order of 0.1 to 1.0 fL will permit rapid adaptation (30 seconds or less) for easy targets and tasks, and
- 3) That red lighting cannot be provided which will permit easy reading for dials and print and still provide immediate dark adaptation for difficult targets.

Since the increase in adaptative effectiveness of decreasing brightness levels is a progressive continuum with no definite inflections, it appears that adaptation data cannot be used to define upper or lower working levels for red lighting. It is obvious that the lower limits cannot be less than that which permits accurate work performance on supra-liminal tasks. Dial readings and actions must be executed, not with 50% accuracy but with 99% accuracy.

Daily operational tasks are usually well above 50% threshold levels. Most of the things we are required to see are easy to see--that is, supra-threshold. Therefore we are interested in psychophysical techniques which directly determine the minimum lighting levels at which ordinary visual tasks can be accomplished with accuracy. One method consists in recording the percent error scores (or the speed) made on a variety of supra-threshold tasks and adjusting the curves to coincide at the plateau of good performance recorded at the higher levels of illumination used in each experiment.

The data in Figure 2 are therefore drawn from studies using time and error scores for foveal performance on supra-liminal tasks under low illumination. Again it is necessary to discount the exact levels of performance. For one thing, several experimenters have shown differences in acuity under red and white light at low levels and it has been necessary to include low white light studies because so little data of this sort has been taken with low red lighting. Furthermore, it has been necessary to adjust the data arbitrarily (by no-doubt disputable means) in order to facilitate visual comparison. However, no matter what manipulation is given these data it cannot disguise the one fact which we wish to demonstrate - that the breakpoints occur in the log unit between 0.01 and 0.1 foot-lambert.

The breaks in the curves for fine detail occur around 0.1 fL. Such material includes: printing in 4-point type size--used in many manuals, mathematical tables and check-off lists; poor quality mimeographing; slide rules and calculating devices; penciled log entries; most navigation charts of present design; and some gauges, dials, recording equipment, engraved name plates.

The breaks in the curves for coarse detail are around 0.01 fL. Such visual targets include most standard dials, switches, control knobs and items in the preceding list which have been redesigned for easier seeing.

Therefore our approach to setting red illumination levels in submarines has been to examine the necessary operation to be performed at each station and then select the minimum level of red lighting required for accurate operation in that area. Where there is decided conflict between this result and subsequent dark adaptation requirements for the operator it is necessary to redesign the instruments, reorganize the procedure, or devise other means of transmitting information.

Close attention has been given to the data in Tables 1 and 2 in preparing specifications

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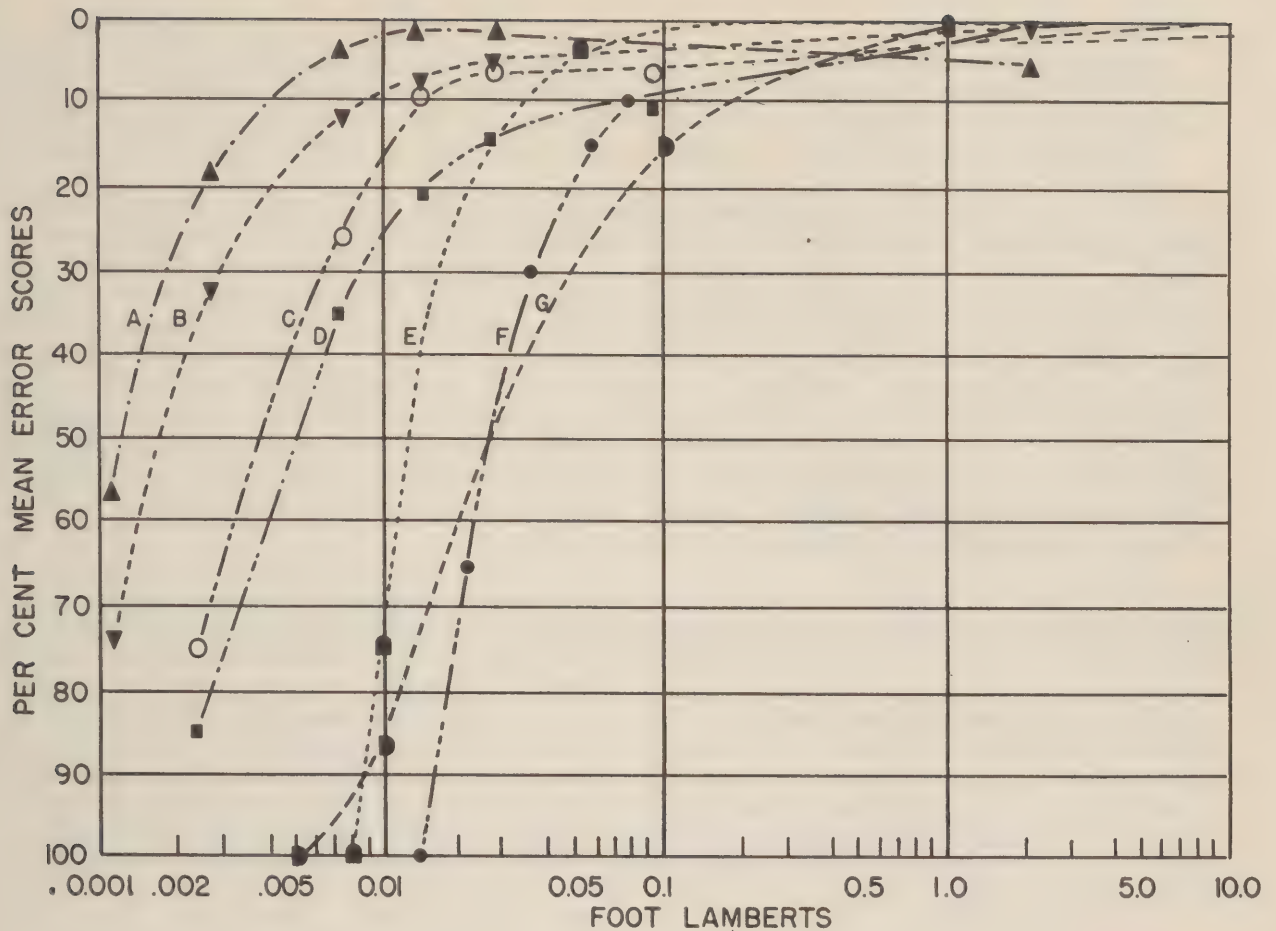


Figure 2. Visual performance at low brightness levels. Per cent mean error scores adjusted to best performance.

References:

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| <ul style="list-style-type: none"> A. Large dials--gross criteria B. Large dials--fine criteria C. Small dials--gross criteria D. Small dials--fine criteria | } | <p>Chalmers, Goldstein and Kappauf, "The effect of illumination on dial reading," Wright-Patterson Air Force Base, Dayton, 1950.</p> |
| <ul style="list-style-type: none"> E. Addition Problems--20-pt. type. | <ul style="list-style-type: none"> F. Legibility of letters--20/40 size. | <p>Rock, Milton L., "Visual performance as a function of low photopic brightness levels," Wright-Patterson Air Force Base, Dayton, 1950.</p> <p>Brown, Fred E. "A Study of the legibility of trans-illuminated markings in aircraft cockpits," Aeronautical Medical Equipment Laboratory, Philadelphia, 1949.</p> |
| <ul style="list-style-type: none"> G. Depth perception--Rock, M. L., <u>op. cit.</u> | | |

for submarine compartments, of which a general idea can be obtained from the following summary:

General Readiness Areas	
(Crew's mess, Officers' wardroom)	0.20 - 2.00 fL
Immediate Readiness Areas	
(Staterooms, Chief's quarters)	0.00 - 0.10 fL

General Operating Areas
(CIC and Control Room)

0.01 - 0.20 fL

Periscope and Pre-lookout Areas

0.01 - 0.05 fL

We look back with much dissatisfaction over our 5-year attempt to apply laboratory data to submarine lighting problems concerned with the periscope and topside lookout activities. The facts are sparse and uncertain in application. We believe that the difficulty can be laid to the fact that laboratory experiments do not appear to have been designed with a view to use in operating situations. For example, the whole discussion of red lighting levels for threshold seeing has been founded upon the use of parafoveal targets and on targets of high contrast. These are situations which seldom exist in reality; for instance, I have never heard of a pilot who reported having made a landing by the use of parafoveal vision -- I dare say that he would not even live to make the report. The typical laboratory problem utilizes black and white targets of the highest contrast ratios obtainable but the results are of only academic interest in naval and aviation problems where atmospheric attenuation reduces most targets to very low contrasts.

It is not the function of basic research to supply immediate answers but it should certainly be demanded of government sponsored projects directed toward the solution of military problems. Therefore I urgently suggest that we review our present experimental designs to see if we have organized them in a way which will permit the results to be transferred with safety to the working situation. This will require more careful analysis of the field situation to which we expect the experiment to apply as a preliminary to the design of the experiment. It appears that we have all too frequently put the experiment first and then tried to make the application; this is the method of basic research but when we want to make immediate application to human engineering design we must structure the experiment in terms of the goal. Our present compromises have too often fallen between basic and applied goals and achieved neither.

Discussion:

Col. Byrnes expressed concern about the tendency to underestimate the value of dark adaptation in night flying. A civilian pilot, he asserted, flying a civilian plane for a civilian airline, over lighted cities in the United States, may find that dark adaptation is no problem. However, for the combat pilot in a fighter plane, flying with no moon, over mountainous country, with unidentified aircraft in his vicinity, dark adaptation is a serious matter. Col. Byrnes stressed the importance of aeronautical charts for a combat air force, saying that even charts of the United States should be designed with combat missions in mind, for they might sometime have to be used by combat air forces.

CDR. Farnsworth indicated that he agreed completely with Col. Byrnes on the importance of dark adaptation. He hoped that his remarks would not in any sense be interpreted as a suggestion that present specifications for brightness levels be relaxed, for his intention was simply to suggest that in the past research workers have misapplied their experimental methods in trying to deduce from them conditions for operation work. CDR. Farnsworth advocated a reorientation for research workers, insisting that they should in all cases try to find an experimental method that is certainly applicable to the operational situation involved.

Dr. Wulfeck noted that the discussion of this problem indicated that it would be possible to use higher levels of red light brightness at the present time without hampering dark adaptation. He urged that possible photosensitization effects be investigated, as well as the range of pre-exposure brightness levels with no effect on dark adaptation, so that this knowledge could be utilized immediately.

Dr. Bach expressed the opinion that the dark adaptation function of the cone portion of the retina may be of greater significance than that of the rod portion of the retina, since "significant" objects are normally fixated on the fovea. Dr. Bach presented the view that differences in the evaluation of the importance of dark adaptation might be due to a confusion between the rod and cone adaptation cases.

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PROGRESS REPORT ON THE DESIGN OF AERONAUTICAL MAPS
AND CHARTS FOR USE UNDER RED LIGHT

Joseph W. Wulfeck

Tufts College

The problem of design of aeronautical charts for use under red light can hardly be separated from the problems of design of aeronautical charts for general use. The use of red light simply creates a special instance.

At present, red light legibility of charts suffers from shortcomings in design of charts for general use. Let us take a moment to look at some of the general problems in chart design. An adequate job of selecting information to appear on aeronautical charts has yet to be done. We have no systematic body of data to tell us what information must be retained for either day or night navigation and what information could be discarded in an effort to reduce cluttering.

We are especially lacking in knowledge as to the best way to designate elevations.

Legibility and interpretability of symbols presents still another problem although work is currently being done on the visibility and legibility of geometric forms, including typography.

It is clear that, in the long run, red light legibility and utility of charts will depend to some extent on general chart legibility and utility.

The characteristics of the red light currently specified for night cockpit illumination create the special problems in the design of aeronautical charts. The wave length property makes it impossible to distinguish hues, and the low intensity makes it difficult, and sometimes impossible, to decipher fine print and other details, especially in the presence of cluttering.

We are concerned then with the following three kinds of problem: (1) colorimetric, (2) typographic, and (3) cluttering.

Two general lines of attack on these problems seem possible. The first would involve no changes in the charts themselves. The simplest example of this is the use of additional light for chart reading in exposures short and dim enough not to impair dark adaptation significantly if such a range of exposure brightnesses and durations exists. Another possibility might be the maintenance of some dark adaptation in one eye while reading charts with the other eye under somewhat increased light. However, it is clear that neither of these would solve all the problems. The second attack might be on the charts themselves. Several ways of changing the charts have been considered:

1. One might adapt the charts primarily for night use and abandon features that would be useful only under daylight. This would mean no use of color. Much detail would be eliminated and type size would be increased.

2. A second plan might involve retaining all the present features of the charts, but

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making some changes to improve discriminability under night lighting. This would mean increasing the size of some of the smaller type. It might mean eliminating the use of small areas of shaded colors as in radio beams and some rearrangements for the purpose of reducing cluttering.

3. A third approach to the problem could be made by separating the day and night aspects of the charts. Separation could be obtained by two methods. The first would be simply to print two editions of the charts on separate sheets or on the two sides of the same sheet. The second would be by colorimetric separation. By this scheme all the present detail might show under white light, but only those features which could be discriminated under the special conditions of red light would show under red. In general, the daylight features could appear in any color, but the night features in colors toward the short wave end of the spectrum, with features which were not to appear at night in colors toward the long wave end of the spectrum.

We have been working on the development of color separation techniques, and are going ahead under three assumptions: (1) colors will be used, (2) 11 colors in an hypsometric series are desirable, and (3) the C-4 cockpit lamp will be used.

Colorimetric separation techniques avoid the necessity of printing two charts or of printing on both sides of the same chart, and at the same time retain the daylight appearance of charts. They also effectively reduce cluttering and leave more room for manipulation of other variables.

The colorimetric aspect of the problem becomes critical when hue is lost under red light, since so much information on charts for general use is color coded. Without hue, only texture and brightness differences between areas remain. Under low level red light, texture differences may be obscured so that only brightness differences remain. Consequently, if the same information that is color coded under daylight is to appear under red light, much of it must be brightness coded.

Brightness coding requires, for example, that a pale blue designating water masses and a light tan designating coastal land masses differ noticeably in red light reflectance.

Brightness coding becomes even more important in designation of elevation. Currently, elevation is designated by a hypsometric series varying in color from a yellowish green through a yellowish tan to a yellowish brown, through eleven steps. Each color represents a given elevation range and elevation increases from green to brown. The first question to be answered is whether or not the hypsometric series now in use yields a series of noticeably different red light reflectances. While he was at Tufts, Lt. S.C. McLaughlin tackled this problem (2). He obtained colorimetric specifications of the map tints currently used in the hypsometric series. Since the only characteristic of the tints that is important under red light is the relative luminosity under red light, those data were obtained so that the brightnesses of the tints under red light could be compared. Unfortunately, however, the relative luminosity scale does not yield equal brightness differences for equal numerical differences. However, the Munsell Value scale does, so Lt. McLaughlin transformed the red light relative luminosities of the tints into Munsell Values. He also found data which indicated that a .02 Munsell Value difference is necessary for a perceptible brightness difference under optimal conditions (3). With this information he was able to show that the present chart tints neither distribute themselves in a regular progression from light to dark nor do they, in all cases, differ perceptibly in brightness from adjacent tints under low level red light.

If the entire Munsell Value range were available, it would be a simple matter to space eleven clearly different hypsometric tint brightnesses, plus three additional for other

features, evenly over the range. Unfortunately, the matter is complicated by the fact that almost all chart areas must bear overprinting. Lt. McLaughlin obtained colorimetric specifications of the black and blue inks currently used for overprinting and found that they had Munsell Values between 2.0/ and 3.0/. This fact, he reasoned, should eliminate the Munsell Values between 0.0/ and 3.0/ from the hypsometric series since overprinting of the Values found would probably be indistinguishable from backgrounds in the 0.0/ to 3.0/ range under low level red light. Furthermore, it seemed clear that the Value difference necessary for legibility of overprinting would greatly exceed any just noticeable Value differences between overprinting and background tints. Making the best estimate possible from scanty data, Lt. McLaughlin established a Munsell Value difference of 3.0/ between overprinting and background as minimum for the legibility of 6-point type under low level red light.

The range with 3.0/ as its lower limit and 6.0/ as its upper limit, Lt. McLaughlin called the "legibility gap." Apparently, this is the first use of the term and it seems to be a pretty good one for it represents the Value or brightness gap necessary for legibility of overprinting.

The presence of the legibility gap and the elimination of the 0.0/ to 3.0/ Value range leave only the 6.0/ to 10.0/ Value range for the hypsometric series. However, untinted map paper is assumed to have a Value of about 9.0/, so the range is restricted to 6.0/ to 9.0/. With 14 tint brightnesses evenly spaced over this Value range, adjacent tints can differ by a value of .21.

In short, recommendations based upon the colorimetric analysis were that a legibility gap of 3.0/ and 6.0/ be maintained and that tints differ by Munsell Values of .21 through the 6.0/ to 9.0/ range. A summary of these data is presented in Table I (2).

We have undertaken a program to determine, among other things, the limits of the legibility gap. Because the upper limit of the legibility gap is limited by the legibility of type at a given contrast with its background, this program requires, in addition to the colorimetric work, research in two directions. The first calls for an experimental determination of the brightness contrast necessary between a surface tint and overprinting in order to insure adequate legibility under low level red light. The second consists of experimental determination of optimum levels of various typographical variables for maximum legibility at given contrasts under low levels of red light.

Two of our experiments may be taken as examples of each direction of research. Experiment VI dealt primarily with the relation between contrast and illumination. Experiment VII concerned typographical variables. Since the details of Experiment VI can be found in AF Technical Report #52-85, we will only summarize it (1).

The only typographical variable was type size. Six- and 8-point type with favorable levels of other characteristics were included as the two sizes of most immediate concern. A crossout task was used which required the subject to read a geographic name, and to cross out, from a group of scrambled letters, all the letters which appeared in the name. All the geographic names were of six letters. Except for the capital at the beginning of each geographic name, the copy was set in lower case.

In addition to 6- and 8-point type size, the experiment covered red light illumination levels from 0.014 to 0.129 foot-candles and background reflectances of 0.26, 0.49 and 0.87.

The general plan of the experiment required measures of performance as a function of illumination for each of the three background reflectances with each of the two type sizes. The six reflectance and type size combinations varied in difficulty, and the illumination

ranges within which meaningful scores could be obtained varied correspondingly. Therefore, six partly overlapping illumination ranges were established within the 0.014 to 0.129 foot-candle range and four values were selected in each.

TABLE I

Cartographic function and red light Values for USAF Aeronautical Chart Tints, and proposed red light Values and relative luminosities.

<u>Sample Designation</u>	<u>Purpose</u>	<u>Present Munsell Value (Red Light)</u>	<u>Proposed Munsell Value (Red Light)</u>	<u>Proposed Relative Luminosity</u>
Untinted Paper	Border	9.00**	9.00	78.66
Yellow	Metropolitan Area		8.78	74.02
H.S. 1*	H.S. 1	5.75	8.57	69.78
H.S. 2	H.S. 2	7.57	8.36	65.70
H.S. 3	H.S. 3	7.66	8.14	61.61
H.S. 4	H.S. 4	7.80	7.93	57.87
H.S. 5	H.S. 5	7.77	7.71	54.11
H.S. 6	H.S. 6	7.73	7.50	50.68
H.S. 7	H.S. 7	7.62	7.28	47.23
H.S. 8	H.S. 8	6.96	7.07	44.08
H.S. 9	H.S. 9	6.67	6.86	41.07
H.S. 10	H.S. 10	6.42	6.64	38.05
H.S. 11	H.S. 11	6.04	6.43	35.30
133 Line Half-tone Blue	Open Water	7.24	6.21	32.55
Golden Buff	Inadequate Relief Info.	7.87	6.00	30.05
Contour Brown	Topographical Symbols	5.49	< 3.00	< 6.56
Road Gray	Highways and Roads	5.28	< 3.00	< 6.56
Aero Red	Radio Information	5.84	< 3.00	< 6.56
Blue	Hydrographic Features	2.45	< 3.00	< 6.56
Black	All Other Lettering	2.85	< 3.00	< 6.56

*H.S. is used here as an abbreviation for "hypso-metric scale." The tints comprising a hypso-metric scale represent different elevation intervals.

**This is an assumed datum, and is not based on the measurement of a sample.

This gave 24 combinations of variables in the design. Each of 12 subjects was given each combination once in a design balanced for experimental variables, their combinations, forms, and serial position. Each trial was limited to one minute. Speed and accuracy scores were derived.

Figure 1 shows speed as a function of illumination for the three background reflectances and two type sizes. Figure 2 shows the corresponding data for accuracy. To make clearer the relation between performance and background reflectance, the data shown on the first two slides have been replotted. Figure 3 shows speed as a function of background reflectance for the two type sizes and various illumination levels. Figure 4 shows the same

relation for accuracy.

The expected improvement in performance with increasing illumination, reflectance, and type size shows clearly in the curves. From them we can conclude that the legibility of 6- and 8-point lower case black print falls off at an accelerated rate as (1) the level of red illumination is reduced from 0.129 to 0.014 foot-candles and (2) reflectance of background is reduced from 0.87 to 0.26. The legibility is less in all cases for 6-point than for 8-point.

One may wonder why the impairment of performance produced by decreasing reflectance shown by the curves is not larger in view of the wide range of background reflectance. This is probably due to the fact that, although the reflectance range is large, the contrast range is small. If 0.049 is taken as the reflectance of the printing ink, the contrast range is only from 0.81 to 0.94.

In order to relate these data to Lt. McLaughlin's colorimetric analysis we may compute contrasts between black ink and his proposed limits for the hypsometric series. These values fall between contrasts of 0.81 and 0.92 and are within the range covered by Experiment VI. In this situation we would expect decreasing contrast in Lt. McLaughlin's proposed hypsometric series to impair performance by no more than the impairment shown in our experiment.

However, the application of these data to operational situations is subject to some qualifications and precautions. The type used for the experiment was selected for maximum legibility under low illumination. It is probable that any type less suitable would show even greater impairment of reading performance. It is also necessary to recognize that overprinting on charts is often subject to special conditions which hamper legibility, as crowding from adjacent materials and sometimes actual superimposition of various kinds of secondary lines. Furthermore, any ink with a reflectance greater than the black used would be expected to increase impairment

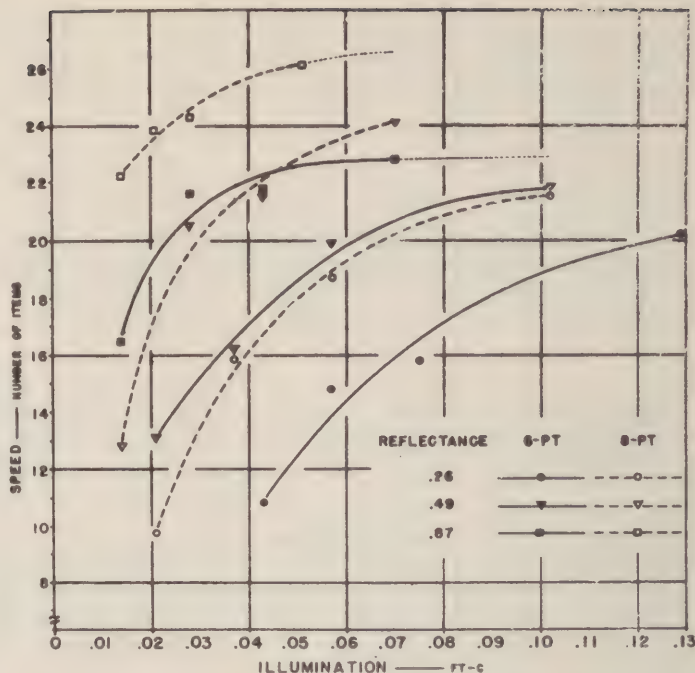


Figure 1. Speed on cross-out task in terms of items right plus errors, as a function of illumination level. Mean scores, 12 subjects. The curves for reflectance 0.87 have been extrapolated to provide additional points for the derived graphs of Figure 3.

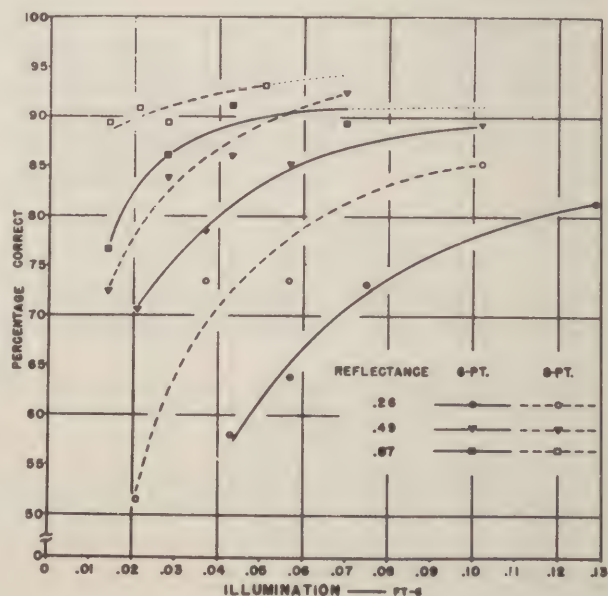


Figure 2. Accuracy on cross-out task in terms of items right as a percentage of items right plus errors, as a function of illumination level. Mean scores, 12 subjects. The curves for reflectance 0.87 have been extrapolated to provide additional points for the derived graphs of Figure 4.

further. It is probably advisable to consider the impairment produced by our experimental variables as near the minimum that would be encountered operationally.

Experiment VII illustrates the attack upon the typographical variables which can be expected to influence the lower limit of the legibility gap. The letter cross-out task was used as in Experiment VI. White light at approximately 13 foot-candles and red light at .086 foot-candles were compared. Primary typographical variables were letter spacing, stroke width and mean letter width. We might point out here that type commercially available does not provide an adequate range of typographical variables and the particular combinations of them required.

We solved this problem by designing our own type and buying our own printing press. Type faces were drawn to specification in the laboratory and were specially cast. All characters were cut, inspected and filed to specification in the laboratory. The copy was then set up and printed with proper combination of the experimental variables on our press. It was touched up by hand and carefully photo-reduced to the proper size. Photoengraving yielded plates from which the final copy was printed.

The results of Experiment VII have not yet been completely analyzed, but several effects are indicated. As expected, low level red light yields poorer performance than moderate white under all conditions. Differences in performance among the various typographical variables and different levels of them are small under moderate white light, but increase considerably under low level red light. Quite different functions between performance and the typographical variables studied are obtained under white and low level red light. The data suggest optimal levels of the typographical variables above and below which performance is impaired under low level red light. When the data are finally analyzed we should be able to relate them to the lower limit of the legibility gap and proceed to determine the optimum characteristics of type for use under low levels of red light and at less than maximal

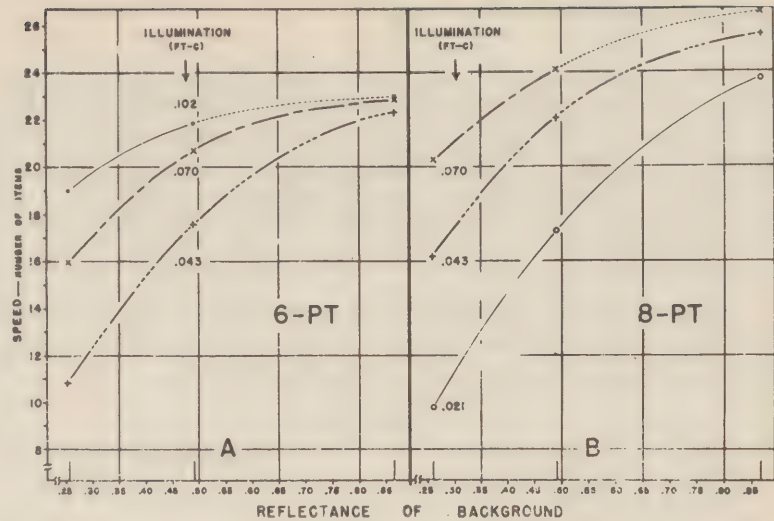


Figure 3. Speed on cross-out task in terms of items right plus errors, as a function of reflectance of background. Mean performance, 12 subjects. Derived from curves of Figure 1. The points for reflectance 0.87, highest illumination in each type size, are based on extrapolated segments of Figure 1 curves.

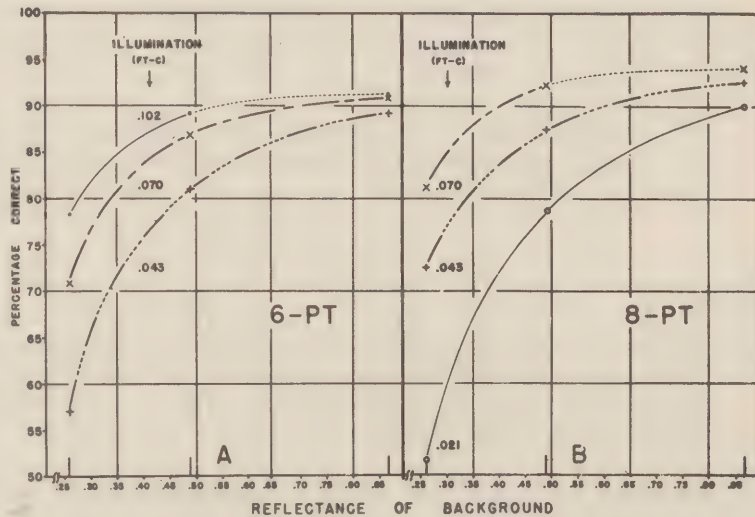


Figure 4. Accuracy on cross-out task in terms of items right as a percentage of items right plus errors, as a function of reflectance of background. Mean performance, 12 subjects. Derived from curves of Figure 1. The points for reflectance 0.87, highest illumination for each type size, are based on extrapolated segments of Figure 1 curves.

contrasts with the background.

In conclusion, we might mention briefly a secondary activity of the group at Tufts. For some time evaluations and recommendations have been written on the frequently revised experimental radio facility charts produced by the Aeronautical Chart Service. These charts are devoid of hypsometric series and other detail and illustrate the design of charts for special, limited operational conditions. The Tufts group is currently experimenting with the design of a radio facility chart which they hope will contribute to the final design of the charts.

The work at Tufts is being conducted under contract with the Aero Medical Laboratories at Wright -Patterson Air Force Base with Captain Charles Seeger as project engineer and Dr. Mason N. Crook as project director.

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Discussion:

- Dr. Sloan called attention to the question of the equivalence of red and white light for use with the cone system. She pointed out that of course red and white light will have equal effect on the cone system, since the photometry of red and white light is based upon the photopic sensitivity curve.
- Col. Grether expressed the opinion that dark adaptation has been overemphasized in combat flying, since actually pilots flying with instrument lights on are unable to fully utilize maximum dark adaptation. Pilots are unable to use maximum dark adaptation because of light from the instrument panel reflected into their eyes by the windshield. Furthermore, when the pilot looks over the instrument panel, there is some glare, that is, light scattered on to the foveal area of interest from the peripherally located instrument lights. Col. Grether stated his belief that when instruments are not used, maximum dark adaptation is used and is of great importance but that when instrument lights are not used, maximum dark adaptation is not relevant.
- Col. Byrnes suggested removal of clutter from air maps, maintaining that there is actually much information on aeronautical charts that becomes less and less important as the speed of aircraft increases. Much information that was necessary at 100 MPH is not needed at all at 60 MPH.
- Dr. Wulfeck thought it would be an excellent idea if the Vision Committee could undertake studies to find out what information pilots think they need on aeronautical maps and what information could be profitably eliminated from the maps.

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Mr. Fred Brown commented that Dunlap & Associates were presumably attempting to determine informational requirements on aeronautical maps under a contract with the Navy Special Devices Center.

CDR. Farnsworth reiterated his idea that researchers have been off the track in their laboratory work and have sometimes failed to find out what the applicability of their experiments will be. He felt that no one could specify to what extent rod vision or cone vision is being used in an operational situation, what portion of the fovea is used, etc., because laboratory workers have not carefully enough oriented test methods to take account of the possible effects of low contrasts, reflection from the windscreen, and other factors that make up the pilot's whole job situation.

A STUDY OF THE SUBJECTIVE DEPTH VALUES AND PRECISION OF STEREOSCOPIC DEPTH PERCEPTION WITH DOUBLE IMAGES

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At the Vision Committee meeting a year ago I discussed the problem of stereoscopic space perception for objects in space whose images in the two eyes may be so disparate that they are actually seen double. It was shown, however, that there were limiting disparities, beyond which stereopsis ceased. These limiting disparities were found to increase rapidly with peripheral angle from about 20 minutes of arc at the fixation point to over a degree at 8 degrees from the fixation point. These data were taken with an apparatus which excluded empirical spatial localization clues. The disparities were introduced by the special mounting of 50%-50% reflection-transmission mirrors before the two eyes. A rotation of these mirrors about vertical axes controlled by suitable lever arrangements introduced the disparity between the images of a test object seen by reflection.

This is a preliminary report about the precision and the spatial correctness of stereoscopic spatial localization within these limiting disparities.

To the apparatus previously described a reference object nearly identical to the test object consisting of an illuminated needle was mounted on a suitable arm so the needle seen also by reflection from another 50%-50% mirror could be located at any distance before or behind the plane of the fixation point and at any lateral distance from that point. This needle would be adjusted for given lateral and sagittal distances from the fixation point. Then the position of the test needle was adjusted to lie at the same angular distance as the reference needle but on the other side of the fixation point. With the position of the eyes maintained on the fixation point, the disparity of the images of the test object was adjusted by the observer until that object appeared by stereoscopic vision to be at (1) the same sagittal distance as the standard needle; (2) at half the sagittal distance from the reference standard from the fixation point; (3) at the same distance in front of (or behind) the fixation point as the standard was behind (or in front of) the fixation point. The illumination of the standard and test needle objects was controlled by the same electrical circuit and the two objects were exposed simultaneously for only 0.2 seconds. This exposure time was short enough to prevent small involuntary changes in fixation to affect the results. The method of adjustment was used to obtain the data.

A distinction must be made, of course, between the precision with which the test object can be adjusted to a given subjective criterion and the spatial correctness of that setting. For example, if the test object is adjusted to appear only half as far from the fixation point as is the reference object, and if the distance of the latter was actually perceived too near, then the adjusted object, though adjusted with great precision would nevertheless not actually be half the depth. That is, the subjective depth values associated with the disparity measured would be objectively in error.

Let us consider first the precision of the settings. The results obtained by two observers (one trained, the second entirely inexperienced) are those that might to some extent be anticipated. For if there are limiting disparities beyond which no stereopsis exists, we would expect the precision to decrease as the disparities approach those limits. Secondly, if the stereoscopic depth impression involves an interaction between separated terminal dendrites, say, on the cortex, we might also expect that the intensity of that reaction would decrease with the separation of the dendrites involved.

Figure 1 illustrates the standard deviations of settings of the test object for apparent equality of depth for one subject for peripheral angles of 1° and of 4° . The rapid increase in the standard deviations with increase in disparity is apparent and the standard deviation becomes very large near the limiting disparity. The greater the peripheral angle the larger are the standard deviations and the greater is the disparity before the standard deviations become infinite. That such settings with double images can be precise has, of course, been shown previously by Tschermak and Hoefler, by Aall, and by Burian.

If we convert the standard deviation of the angular disparity to depth in centimeters for the observation distance of 50 cm., we obtain a graph as shown in Figure 2. Plotted in this figure are the standard deviations for settings for equality, half-depth, far equals near depth, and twice depth. The last three sets of data are plotted against the distance corresponding to the disparity of the setting and not that of the reference standard. These data suggest therefore that the subjective depth of the standard tended to be invariant during the adjustment of the test object, because the standard deviations according to the same mean distance of the setting were of the same order regardless of the subjective criterion.

These data also tend to substantiate the hypothesis of Tschermak that the precision of stereoscopic depth perception increases the nearer the test object is to the horopter.

Now consider the correctness of the subjective depth values associated with disparity, even when that disparity is so large that the images are seen double. Figure 3 shows the data for one observer for a peripheral angle of 1 arc degree. On the graph are the data for the settings of the same depth (equality), those for the half-depth, and those of the near depth made equal to the far depth. The abscissa is the distance in centimeters of the reference standard object from the objective fronto-parallel plane, that farther than the fixation point to the right, that nearer the fixation point to the left. The ordinates are the mean position of the settings of the test object also in centimeters, those above being distances beyond the fixation point, those below being the distances nearer than the fixation point. These distances

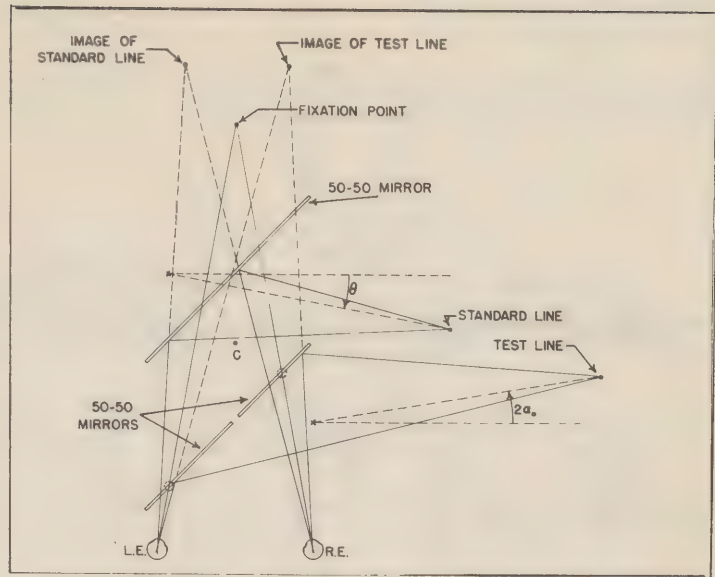


Figure 1.

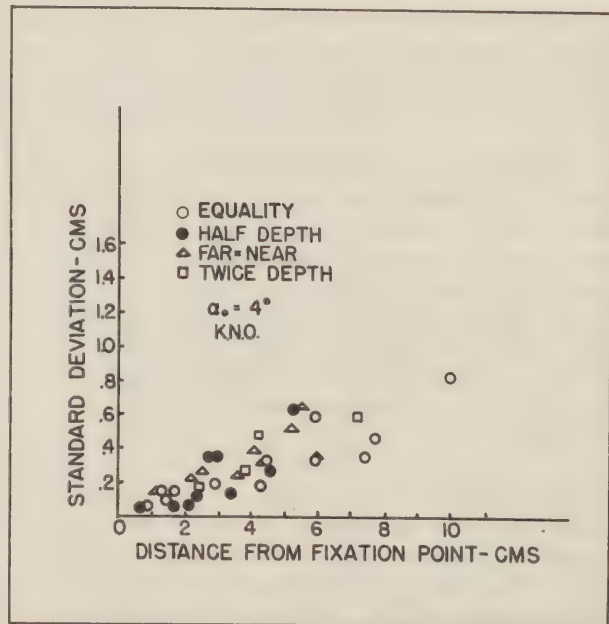


Figure 2.

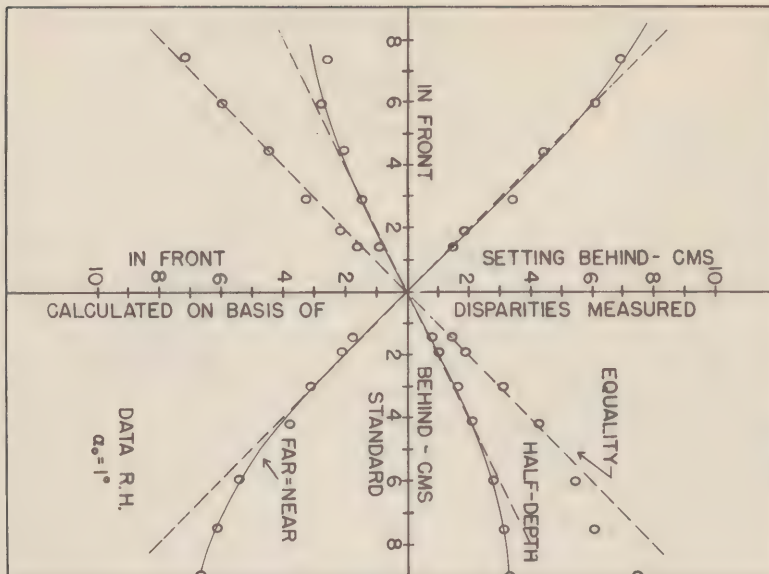


Figure 3.

must mean that the subjective depth values associated with these large disparities do not increase continuously, but reach a limiting value. This is consistent with our earlier qualitative results in which as the disparity increases the test object though seen in double images seems to reach a limiting depth.

This same conclusion is borne out by the data obtained by adjusting the test object so that it appeared the same distance in front of (or behind) the fixation point as did the standard object appear behind (or in front of) that point. The range within which the images of the objects appear single (fused) for this peripheral angle is between 1 and 2 cm. in front of and behind the plane of the fixation point. Hence it is clear that stereoscopic depth is still accurate for quite a range of disparities though the images are actually seen double.

As the peripheral angle of the standard and test objects increases, greater are the limiting disparities within which stereopsis occurs. Similarly greater are the disparities within which correct stereoscopic perception of depth occurs. This is borne out by Figure 4.

More important for our purpose here is not the departure from correct depth values, but the fact that over such a large range our subjective depth values corresponding to certain angular disparities are in fact so correct.

are calculated from the mean angular disparity as measured and read from the dial indicator on the instrument.

The equality of depth settings tend to follow accurately the expected one to one relationship. In this particular graph there appears to be a departure for large disparities corresponding to more distant objects. This departure is not usually found.

Adjusting the test object for just half the apparent depth of the standard object, the data show a remarkable correspondence to exactly half depth until the distances behind or in front reach about 5 to 6 cm. from the fixation point. There the data points level off. This

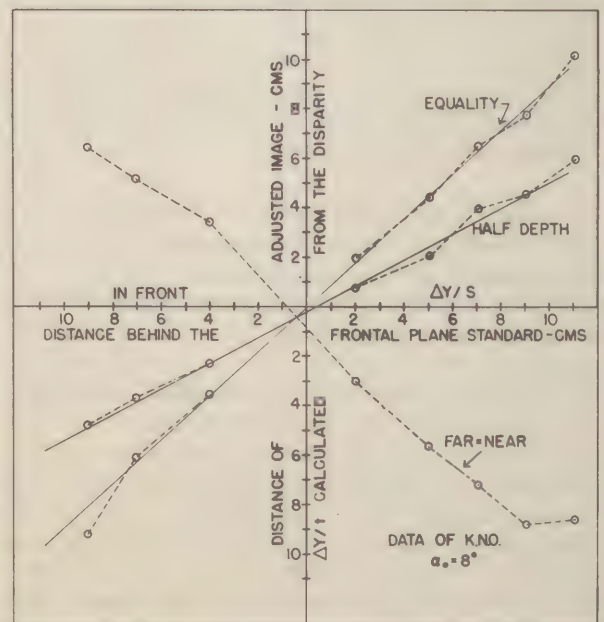


Figure 4.

There are other aspects of these preliminary data that are important to visual physiology but not of immediate value to this report.

The conclusion is, of course, that stereoscopic depth localization is precise and the subjective stereoscopic depth values remarkably correct within certain limits, even though the objects are seen in double images.

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Discussion:

Dr. Gibson expressed interest in why Dr. Ogle was worried about the apparent lack of correlation between double imagery as an objective sensory phenomenon and the immediate impression of depth. Dr. Gibson proposed that perhaps the so-called sensations of double imagery are epi-phenomena. It was Dr. Gibson's opinion that sensations of double imagery are not the basis of depth perception.

Dr. Ogle agreed with Dr. Gibson.

Group Capt. McCulloch emphasized that objects are not always oriented side by side in space but have spatial relations in other planes than the horizontal. He asked if Dr. Ogle could give any information about the effect of double imagery in other than the horizontal dimension.

Dr. Ogle replied that work had not gone beyond the horizontal dimension.

THE STEREOPTOMETER--AN INSTRUMENT FOR THE STUDY OF BINOCULAR VISION

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The instrument to be described in this paper was developed at the Army Medical Research Laboratory to incorporate the psycho-visual task of the stereoscopic range finder in a device amenable to laboratory manipulation. Such an instrument was desired for use in the study of factors in the individual, the range finder, and the target field which affect stereoscopic range-finder performance.

The stereoptometer is, in principle, a stereoscopic range finder (2, p. 254) of unit base and unit magnification, or a Haploscope (4) in which the adjustment for accommodation has been sacrificed in the interest of mechanical simplicity and precision of vergence measurement. A reflex sight (2, p. 241) is utilized to project into the field of view of each eye of an observer a star point or other reticle without interposing optical aid other than ophthalmic prescription between the observer and his field of view. These projected reticle images may be fused to constitute a test object manipulable in depth by the adjustment of the angle of vergence between the parallel beams of light used to project the reticles.

Elements of the Instrument

The functioning of the instrument depends upon control of the interrelation of the reflex sights before the two eyes. To establish this control a three-part mechanical system is employed which serves to support, rotate, and measure the angle of vergence between the sights. A review of the characteristics of the reflex sight will help to delineate what is required of the mechanical system.

The Reflex Sight

The reflex sight (Fig. 2) is essentially a collimator with a half-reflecting surface to permit indirect viewing. It consists, in principle, of a light source, a reticle, a lens, and a half-reflecting surface. The net result is to produce a parallel beam of light carrying the image of the



Figure 1. The Stereoptometer. The reflex sights, the right bearing and arm assembly and the dial gauge with its slide-bearing mount are plainly visible. In the photograph, the left arm is pinned by a large knurled-headed taper pin to establish asymmetrical right vergence.

reticle. When this beam is observed by an eye looking into the half-reflecting surface, the image of the reticle is localized at an indefinite distance in front of the observer.

The reflex sight may take many forms, depending upon the optical precision required and the proposed employment. In a preliminary model (1) of the stereoptometer, a reflex sight utilizing a Mangin mirror was used. In the current instrument, an optical system much as diagramed is employed.

Characteristic of images carried by parallel beams, the reticle projected by the reflex sight is localized on the line of sight of the observing eye. Lateral displacement of the observing eye results in a like displacement of the reticle image, rotation of the observing eye results in a contrary displacement of the reticle image. The first of these characteristics of parallel beams makes unnecessary an adjustment for interpupillary distance when two beams of sufficient width are used. The second makes possible the act of ranging. Also, as parallel lines form equal angles with transverse parallels, measurement of the vergence angle of the eyes in setting the simulated test object is possible by the angle of vergence of the parallel beams even though the axes of rotation of the reflex sights do not coincide with those of the eyes.

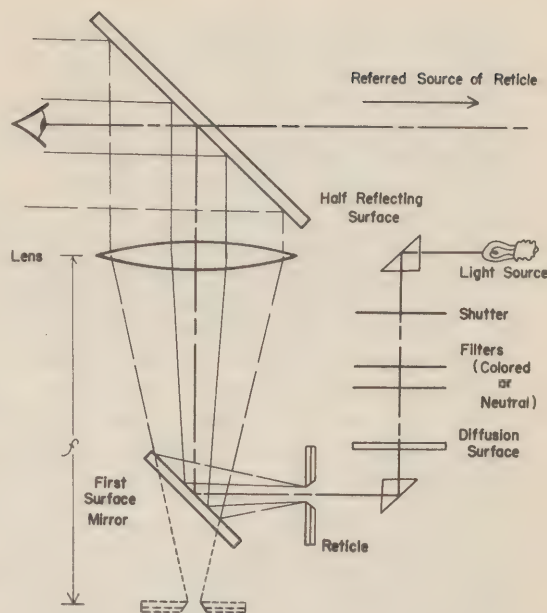


Figure 2. Schematic diagram of a reflex sight.

The Mechanical System

The mechanical system of the instrument may be considered in three parts. Each was designed to be independent of the other in function for simplicity of construction and to avoid interaction in operation. These parts are the bearing and arm assembly, the drive screw assembly, and the dial gauge and slide-bearing assembly. These three parts of the mechanical system are necessary whether one or both of the reflex sights are verged.

The bearing and arm assembly provides a stable and rotatable mount for the reflex sights as well as a rigid arm through which to apply the rotational force and from which to measure the angle of vergence. In the current instrument, two of these assemblies are used--one for the reflex sight before each eye. The basic element of the assemblies is a three-inch, precision-ground, ball, thrust bearing.

The drive screw assembly (Fig. 3) provides the force, acting against a spring to diverge the bearing and arm assemblies. The drive screw is set between the arms, and is of dual pitch in a 2:1 ratio. The dual-pitch screw was selected rather than the more usual left and right thread as it permits the use of a split-nut as the reference point for symmetrical convergence. This makes possible adjustment to eliminate play or slap which would show up as lateral weave of the test object when the direction of movement is reversed. The dual-pitch screw also permits two additional reference points for movement to provide a choice of either asymmetrical right or asymmetrical left vergence. The resultant angular speed of radial movement of the test object in all three conditions is the same. Independence of the screw assembly from the arm and bearing assemblies is obtained through the use of pressure contact points where the screw assembly meets the arms.

The dial gauge and its slide-bearing mount is also located between the arms. The

dial gauge is so mounted as to permit the use of a single gauge to record the movement of either or both arms, and to give direct reading for all conditions of vergence. This placement of the dial gauge requires that the length of the gauge and the distance between the pivots of the arms be approximately equal, the dial gauge longer than the distance between the arms within a length equivalent to the tangent of two to four degrees. This requirement must be met in order that the instrument may be adjusted to read linearly.

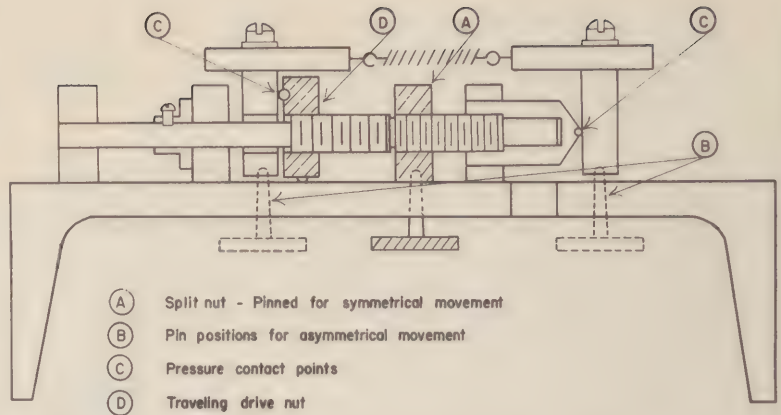


Figure 3. Schematic drawing of drive screw assembly. Thread Ratio-2:1

The dial gauge used in the current instrument can be read directly to one ten-thousandth of an inch and permits two-tenths of an inch of movement. With this gauge placed five plus inches from the pivots of the arms, sensitivity is approximately four seconds of arc per division. To permit measurement of ranges from infinity in to one meter, an angular distance of approximately four degrees, the dial gauge is used through its linear range twice.

Calibration

The instrument triangle associated with each arm was calibrated separately. This was accomplished through the use of mirrors mounted in place of the reflex sights on the bearing and arm assemblies, and a collimated light beam bearing a reference edge. Movement in the instrument triangles was observed over a distance of twenty-five feet in calibration triangles arranged symmetrically about parallels from the pivot points of the arms perpendicular to the facing wall. Four degrees of arc served in the calibration triangle for a two-degree movement in the instrument triangle. Movement of the reflected beam was read in the calibration triangles to a tenth of a millimeter. The product of the calibration was a multiplying constant for each arm to be used in conjunction with the observer's interpupillary distance to convert dial gauge values to ranged distances. The conversion factor is the effective length of the long side of the instrument triangle.

One consideration in the calibration which required a trial and error adjustment was the positioning of the dial gauge between the arms. Since it is desired to measure convergence angles as great as four degrees, and since the tangent function is linear to five places for only two and one-half degrees, it is necessary that the instrument triangles be balanced about their perpendiculars so that approximately two degrees are measured negatively and two degrees positively. The adjustment is critical only for that arm with which the body of the dial gauge moves as the measuring element. For the other arm, where the plunger of the dial gauge is employed as the measuring element, a two-degree sweep in the instrument triangle is used twice over to cover the four degrees.

Alignment of the reticle images projected by the reflex sights with respect to each other is accomplished with the aid of a Keuffel and Esser double collimator.

Cues Available to the Observer in the Test Object

The depth cues available to the observer from the test object would seem to be only the proprioceptive cues of binocular vergence, double images, and disparity between the

images in the two eyes. Yet, certain additional factors are present which may be significant in the perception of the depth placement of the test object. The most obvious of these is a contradictory cue of test object size. The apparent relative size of the test object grows larger with increasing distance, contrary to the behavior of a real object. This is a fundamental property of reticles. It arises from the fact that the reticle subtends a constant visual angle while the receding target subtends an ever smaller visual angle. Concomitant to this is the linear size relation of the test object to the reference object. If both objects are of the same shape, linear perspective may operate to produce errors of localization. Lastly, the relative brightness of the test object with respect both to the background on which it is projected and the target may significantly influence the setting of the test object.

Possibilities of Employment

The data obtained from the stereoptometer provide two measures: 1) a spatial localization measure, the mean range reading; and 2) a stereoptic acuity measure, the variability of the range readings. The appropriate expression of these measures will depend upon whether the instrument is observer or experimenter operated and whether the data are transformed from angular measure to linear measure. Consistent with the approach used, the observer's task may be to place the test object at the same distance from himself as the reference object; or to make judgments of the relative depth position of the test object with respect to the reference object, as the experimenter adjusts the instrument and exposes the test object for timed intervals.

The variables that may be studied in the target field are limited only by the experimenter's ingenuity in manipulation of the environment. With reticle brightness control and a selection of neutral density filters for the half-reflecting surfaces, the test object may be projected by the observer into almost any field of view which one would care to consider. The instrument has been used to investigate the depth dimension of real terrain under field conditions, reduced stimuli and illusion situations in the laboratory, and simulated scenes projected from stereoscopic slides.

The specific instrument reported here has been constructed to study symmetrical, asymmetrical right, and asymmetrical left vergence. Modification will permit study of other instrument factors to include: magnification, optical and base; and verging element, target or reticle.

The condition of symmetrical vergence offers a unique test of binocular vision. A report by the observer of movement in the test object, left, right, or radial, is immediately referable to suppression in a specific eye or binocular vision. Fusional limits may be explored through the report of doubling of the test object image. Modification of the reticle mounts to permit manipulation and the utilization of configurations reported by Ogle (3) would permit study of fixation disparity and aniseikonia.

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Discussion:

- Dr. Sloan asked why it was necessary to have reticle size vary with range adjustment.
- Dr. Harker pointed out that the situation here is that of a moving reticle. In standard range-finders, the target is moved and the reticle held constant. In both situations, the reticle and target change size as range is changed.
- Dr. Sloan asked for clarification. She wished to know if Dr. Harker had stated that in the typical range-finder the test object increases in size with increasing distance. Such an increase in size obviously conflicts with stereoscopic cues of depth. One should imagine that such a conflict would reduce the precision of stereoscopic range-finding. Dr. Sloan then asked if it would not be possible to design a range-finder in which this conflict did not exist.
- Dr. Harker replied that this question had occurred to him about a year ago and he had asked Lt. Col. Alan Gee if it would be possible to maintain target size in a stereoscopic range-finder as range adjustments were made. It was Col. Gee's opinion that it would not be feasible to design a range-finder in which size of target did not change with increasing distance, because of the extremely small tolerances involved.

THE PERCEPTION OF THE DEPTH POSITION OF AN OBJECT AS A FUNCTION OF OTHER OBJECTS IN THE FIELD OF VIEW

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Differences can occur between the apparent and physical depth locations of objects or parts of objects. The latter has been demonstrated by Ames (2) with the rotating trapezoidal window. Also, he has reported that an object attached to the trapezoidal window appeared to vary its position with respect to the window when the window was rotated. The present study had two purposes: 1) to investigate quantitatively the difference between the apparent and physical relative depth position of a binocular test object when differences were present between the apparent and physical relative depth positions of other binocular objects in the field of view; and 2) to formulate a hypothesis from the data which would be useful in understanding and predicting similar phenomena.

Apparatus

The apparatus used to produce the test object and to vary its apparent depth position consisted of a haploscopic instrument. The principles involved in this instrument have been discussed previously (1, 4). When the adjustment knob of the instrument was rotated, a circular orange disc (15 minutes in diameter) appeared to move toward or away from the observer, depending upon the direction of rotation. This binocularly fused projected image was called the test object. The instrument contained no magnification, and only the beam of parallel light entering the right eye was adjustable.

Experiment I

Display

The display used in the observer's field of view consisted of a series of white figures which varied regularly in size. It was made from a piece of white cardboard, parts of which were blackened out to form the nine white separate figures. The front views of Figure 1a and 1b are schematic drawings of the projection of this display on the observer's frontal plane, when the smallest figure was on the left and right, respectively. These two frontal projections were not the identical reverse of each other. The physical position of the display was always such that it formed a 70-degree angle with the observer's frontal plane with the right end 38 cm. farther from the observer than the left end. In the situation illustrated by Figure 1a (the

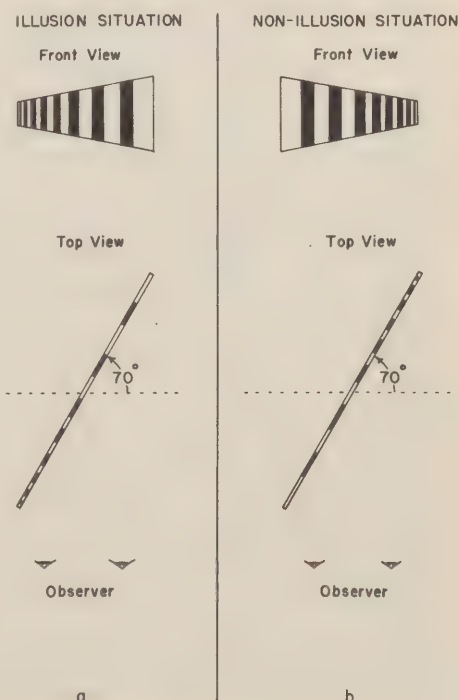


Figure 1. Schematic Drawing of the Front and Top Views of the Illusion and Non-Illusion Display.

illusion situation), the size gradient would tend to make the left end of the display appear to be farther from the observer than the right end. In the situation illustrated by Figure 1b (the non-illusion situation), the size gradient was in the same direction as the relative physical positions of the two ends of the display. With the smallest figure on the left end of the display and the display at its 70-degree angle position, the nine white figures were a geometric projection from the position of the observer of nine equal rectangles lying in a plane which formed a 273-degree angle with the observer's frontal plane (see Figure 2). The display was 40 cm. long, 2.5 cm. and 7.4 cm. high at the ends, and subtended a visual angle of 2 degrees 36 minutes. Four white rectangles were also used. Two of these were 2.5 cm. high and two were 7.4 cm. high. The method of finding the widths of the rectangles is shown in Figure 3. These white rectangles were used one at a time as controls. The brightness of the controls and of the display in this and the following experiment was adjusted to 2.4 foot-lamberts as measured with a Macbeth Illuminometer. The illumination was white, and in this and the following experiment, no objects were visible in the observer's field of view except the test object and either the display or control object.

Procedure

Twelve male college graduates were used as observers. They were instructed to fixate a designated part of the display and to adjust the instrument until the test object appeared to be the same distance from themselves as this designated part of the display. The part of the display selected for this adjustment will be called the reference object. In all cases, the reference object was either the extreme right or the extreme left edge of the display. The use of the nine-figure display will be called an experimental situation. The use of a control will be called a control situation. Sixteen successive adjustments of the test object to apparent depth equality with the reference object were made for each experimental or control situation by each observer. A control was always presented parallel to the frontal plane of the observer at the position previously (or later) occupied by the end of the display for which it was appropriate (see Figure 3). The end of the control which coincided with the position of the reference object in the experimental situation was designated as the reference object in the control situation. This provided a measure of the observer's adjustment of the test object to the depth position of the reference object when there was no series of similar figures of differing size in the field of view. The consequences of adding the series of figures could then be determined. The adjustment of the test object to the apparent depth position of the reference object was made with three different lateral positions of the test object with respect to the reference object. These were set by the experimenter by using the beam of parallel light entering the left eye. These conditions were such that when the observer

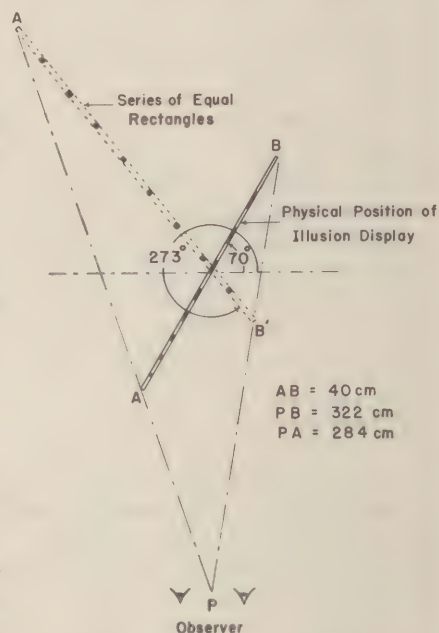


Figure 2. A Schematic Drawing of a Top View of the Illusion Display as a Geometric Projection of Nine Equal Rectangles.

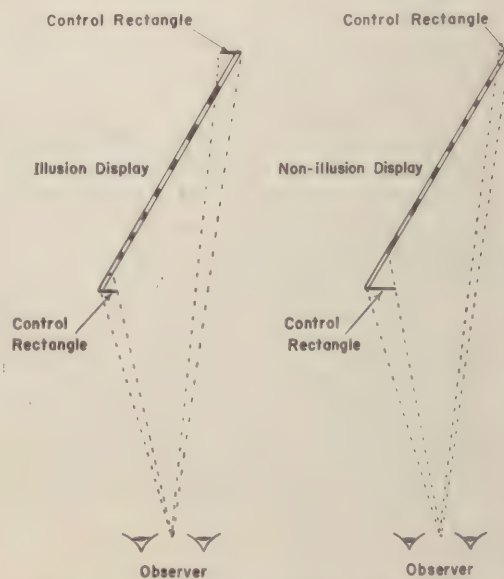


Figure 3. A Schematic Drawing of the Widths of the Rectangular Controls as Determined by the Frontal Projection of the End Figures of the Display.

adjusted the test object to apparent depth equality with the fixated reference object, the test object appeared 1) over the reference object, or 2) peripherally displaced to the other end of the display from the reference object, or 3) peripherally displaced from the reference object to the approximate center of the display. The first two conditions were presented at different times with both the illusion and non-illusion situation. The third condition was used only with the illusion situation.

The vertical and lateral relation of the test and reference object for each experimental situation was retained for its control. The vertical position of the test object in both the experimental and control situations, regardless of which end of the display was used as a reference object, or of the lateral position of the test object, was always located ten minutes of visual angle higher than the top of the largest end of the display. The order of presentation of the different situations was systematically varied between observers. The above remarks concerning procedure apply when appropriate to the second experiment unless a later statement indicates otherwise.

Results

The results from this experiment are given in Table 1. Each result in the table is the mean of 12 scores, one from each observer, where each score is a mean of sixteen adjustments. This also applies to Table 2. The dial reading for each adjustment from each observer was converted to centimeters using the observer's interpupillary distance and the calibration constant of the instrument. The measurements of interpupillary distance were obtained by means of the NDRC Interpupillometer, Navy Model Mark 1. In the outline drawings of the experimental and control situations contained in two of the columns of Table 1, the "R" indicates the position of the reference object and the small circle indicates the position of the test object. The control for each experimental situation is shown in the tables directly below the experimental situation. The t values of the differences between each experimental situation and its appropriate control and the probabilities associated with these t values are also given in Table 1 (and Table 2).

The observers were asked to estimate the apparent position of the display after each set of sixteen adjustments in an experimental situation. For the illusion situation, the average report was that the left end was 6.1 inches (15 cm.) farther away than the right end with the display appearing to lie from near-right to far-left at a 23-degree angle with respect to the frontal plane. With the non-illusion situation, the average report was that the right end was 12.5 inches (32 cm.) farther away than the left end with a slant from near-left to far-right of 43 degrees. One observer in this and in the following experiment was unable to give a verbal estimate of the distance difference between the two ends in either the illusion or non-illusion situation. Physically, the left end was always 38 cm. closer than the right end, with a depth slant of the display of 70 degrees. Thus, there is evidence that in the illusion situation a rather large difference occurred between the apparent and physical relative positions of the ends of the display, and in the non-illusion situation this difference was reduced but not entirely eliminated.

TABLE I
Results from Experiment I

The binocular adjustment of a test object to depth equality with a reference object when the latter is one of a series of similar objects of different sizes at different distances.

		Illusion Situation		Non-Illusion Situation	
			Mean in cm. t and p		Mean in cm. t and p
Test Object above Reference Object	Experimental		328		331
	Control		328		331
	Experimental		294		294
	Control		294		295
Test Object above Other End of Display	Experimental		288		324
	Control		330		330
	Experimental		336		299
	Control		293		290
Test Object above Center of Display	Experimental		315		
	Experimental		313		

An examination of the results in Table 1 shows that the means obtained from those controls which corresponded in position with the right end of the display varied from 328 to 331 cm. The means obtained from the controls which corresponded in position with the left end of the display varied from 290 to 295 cm. Since the right and left ends of the display were 322 cm. and 284 cm., respectively, from the observer, a constant error probably occurred in the conversion of the dial readings to distance. The average difference, however, between the results from the controls for the right and left ends of the display is .37 cm., which is reasonably close to the physical difference of 38 cm.

When the test object was not laterally displaced from the reference object, the differences between the means obtained from the experimental and corresponding control situations were small or zero (see Table 1). However, when the test object was laterally displaced from the reference object to the other end of the display, some large differences between the experimental and corresponding control situations occurred. In the illusion situation, these differences were larger (beyond the .001 level of confidence) than in the non-illusion situation.

When the test object was displaced from the reference object to the approximate center of the display in the illusion situation, differences still occurred between these adjustments and those from the previously discussed control situations. These differences were less, however, than those which resulted from the larger displacements.

Discussion

Consider the case in which a control was used for the illusion display with the reference object on the right and the test object displaced to the left. The mean adjustment to depth equality of the test and reference object was 330 cm. (see Table 1). When the illusion situation was used instead of the control, the mean adjustment was 288 cm. Evidently, if a 330 cm. adjustment of the test object had been made in the illusion situation, the test object would have appeared to be behind the reference object even though, according to the control results, it should have appeared at the distance of the reference object. It seems with the illusion situation that both the left end of the display and a test object in frontal proximity to the left end were seen as farther back with respect to the right end of the display than they would have appeared if the illusion had not been present. This suggests that the apparent depth relation between the test object and the left end of the display was less modified by the illusion than the apparent depth relation between the test object and the right end of the display. An examination of the results from the illusion situation, with the reference object on the left and the test object on the right, permits a similar interpretation. In this case, both the right end of the display and the test object were seen as farther forward with respect to the left end than they would have appeared had the illusion not been present. The results from the situations in which the test object was not laterally displaced from the reference object indicate that, under these conditions, the apparent depth relation between the test and reference object was not disturbed by the illusion. These considerations suggest the following hypothesis: In a binocular situation, a difference between the apparent and physical relative depth positions of objects will least disturb the apparent depth relation between a test object and that object to which it is frontally most adjacent. This most frontally adjacent object is the object whose displacement from the test object subtends the smallest visual angle with respect to the observer. If it is assumed that in the control situations the test object was "correctly" adjusted to the physical position of the reference object, the hypothesis would be as follows: When a difference occurs between the apparent and physical relative depth positions of objects in a binocular situation, the depth position of a test object is most correctly perceived with respect to that object to which it is most frontally adjacent.

Experiment II

Display

In this experiment, the display was a geometric frontal projection of the previous illusion display calculated from the position of the observer. This display was at the depth position of the center of the previous display. All parts of this display were physically located in a plane frontal to the observer. The reference object, as before, was either the right or the left edge of the display. The test object was either above the reference object or laterally displaced to the other end of the display. The controls consisted of two white rectangles. One of these had the height of the right end of the illusion display and the width of the right-most figure. The other control had the height of the left end of the display and the width of the left-most figure. Each end of the display was 303 cm. from the observer. When a control was used, it was placed frontal to the observer at the position previously (or later) occupied by the end figure of the display for which it was appropriate.

Procedure

The same twelve subjects were used here as in Experiment I. The order of presenting the different situations was systematically varied between observers.

Results

The results from Experiment II are given in Table 2. The arrangement of this table is similar to that of Table 1. In Table 2 (as in Table 1), the largest differences between the experimental situations and the corresponding controls occurred when the test object was laterally displaced from the reference object. The average verbal report was that the right end was 4.5 inches (11 cm.) closer than the left end, with a slant in depth from near-right to far-left of 20 degrees.

Discussion

In this experiment, the observers saw the right end of the display as closer to them than the left. With the test object at the right end of the display and the reference object at the left, it would be expected that the observers would move the test object behind the apparent position of the right end until it appeared equidistant in depth with the left end. From the previous hypothesis, it would be anticipated that the resulting mean adjustment would be greater than that from the control for the right end, and, since the two ends were physically at the same distance, also greater than that from the control for the left end. Table 2 shows that this did occur. Also, with the right end as the reference object and the test object at the left, the hypothesis is consistent with the mean result being larger when the control rather than the illusion display was used. A similar kind of explanation can be given for the differences between the experimental and corresponding control situations

TABLE 2
Results from Experiment II

The binocular adjustment of a test object to depth equality with a reference object when the latter is one of a series of similar objects of different sizes at the same distance.

			Mean in cm.	t and p
Test Object above Reference Object	Experimental		312	---
	Control		312	
	Experimental		312	0.89 >.1
	Control		313	
Test Object above Other End of Display	Experimental		306	2.26 <.05
	Control		310	
	Experimental		319	2.74 <.02
	Control		310	

which occurred in Experiment I when the test object was laterally displaced from the reference object. These mean differences are in the expected directions.

General Discussion

In Experiment I, the differences between the control and the illusion situations with the laterally displaced test object were larger than the differences between the similar situations in Experiment II. The difference between the apparent and physical relative depth positions of the ends of the illusion display was also larger in Experiment I than in Experiment II. It is suggested that the difference between the apparent and physical relative depth positions of two objects can be investigated through the method of placing the test object so that it is frontally displaced from one of the objects (the reference object) but frontally adjacent to the other object.

In Experiment I, the verbal report of the observers indicated that the non-illusion display appeared to be somewhat less slanted in depth than it actually was. The differences between the means of the two experimental situations (Table 1) in the non-illusion situation with the peripherally displaced test object is 25 cm. (324-299 cm.). The difference between the respective controls is 40 cm. (330-290 cm.). The 40 cm. difference is greater (beyond the .05 level of confidence) than the 25 cm. difference. This indicates that a reversal in direction of the apparent relative depth positions with respect to the physical relative depth positions is not a necessary condition in order to affect the equality adjustments when the test object is displaced. A change in magnitude, it seems, is sufficient to modify these adjustments.

Assume that there are two laterally separated objects, A and B, such that with binocular vision B appears to be behind A when it is physically in front of A, and also that there is a qualitatively different object, C, which in its frontal projection, with respect to the observer, is closer to B than to A. If C is to appear at the same depth position as B, and if the total perception is to be consistent (3), C must also appear behind A. There are three binocular disparities to consider: that between A and B, that between A and C, and that between B and C. Since B appears behind A when it is physically in front of A, the response to the binocular geometric disparity between A and B is not that which would be predicted from this disparity alone. Therefore, if the perception is to be consistent, the response to the binocular geometric disparity between A and C or between B and C must be modified. The disparity between A and C might be ineffective or that between B and C might be ineffective or there might be some compromise between these two alternatives. The differences between the apparent and physical relative depth positions of A and B, plus a requirement that the perception be consistent, is not sufficient to explain the perception which occurs. The additional factor proposed by this study is that the importance of the geometric disparities between C and either A or B must be considered in relation to the angular visual separation of A, B, and C with respect to the observer. An illusion in depth may be a convenient device for demonstrating this factor rather than a necessary condition for its occurrence. It may be significant in other than illusion situations.

Summary

A difference between the apparent and relative depth positions of laterally separated objects in the binocular field of view was produced by using a series of similar objects of different sizes. It was found that the adjustment of a dissimilar object (a test object) to the apparent depth position of one of these objects (a reference object) depended upon the lateral position of the test object above the series of objects. The hypothesis was made that the depth illusion would least disturb the apparent position of a test object with respect to that object whose distance from the test object subtended the smallest visual angle. It is suggested that the binocular geometric disparity between a test object and a frontally ad-

acent object is functionally more important than that between a test object and a frontally less adjacent object, regardless of which object is designated as the reference object.

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Discussion:

- Dr. Ogle asked Dr. Gogel if he had found any time trend among the 16 successive settings under the same circumstances. Dr. Ogle also asked if it would confuse the subject in the illusion situation if he ever once saw equality.
- Dr. Gogel replied that there was no time trend evident and that subjectively he had not noticed any confusion based upon the presentation of equality.

ANISEIKONIA AND THE HOWARD - DOLMAN TEST*

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Johns Hopkins University

Various tests of depth perception are used at the present time to determine fitness for different occupations (such as automobile driver, airplane pilot, crane operator, operator of stereoscopic range finders, or other similar devices). There is a difference of opinion as to whether or not airplane pilots, for example, need binocular depth perception, (i. e. perception based primarily on binocular disparity). In tasks such as the operation of stereoscopic range finders and map making devices, on the other hand, the necessity for this type of depth perception is self-evident. The problem of finding suitable tests for this visual function is therefore still an important one.

In selecting a test, consideration has seldom been given either to prior analysis of the visual task or to evaluation of the different tests, to determine what particular aspects of depth perception are involved in the task, and what aspects are measured by the different tests. Consider for example, a moving-rod test such as the well-known Howard-Dolman test. The average error score commonly used, measures the mean variation of the settings from the position of true equidistance. This score is determined by two relatively independent aspects of depth perception, namely (a) the absolute error in the judgment of equidistance and (b) the mean variation of the settings from the position of subjective equidistance. Two subjects might, for example, have the same average error score of 35mm., yet be quite different in ability to distinguish small differences in depth. One might make settings of the movable rod about one-half of which were more than 35mm. either in front of or behind the fixed rod. The other might consistently set the movable rod within a few mm. of a point 35mm. behind the fixed rod. The second subject, though he has a constant error, in judging the relative distance of laterally separated objects, can detect very small changes in distance.

The type of response in which the settings of the movable rod deviate consistently in one direction from the zero position has been recognized for a long time. Howard himself in 1919 reported that 23 of 106 subjects showed a significant constant error. At that time relatively little was known about the effects of aniseikonia on space localization, so that Howard was unable to suggest any explanation of the constant errors. In 1944 Dr. Rowland and I wrote a report in which we pointed out that horizontal aniseikonias should produce constant errors in judging the relative distance of the laterally separated rods of the Howard-Dolman test. We suggested that, instead of the average error score, two separate scores should be computed, one measuring the constant error, the other the variability of the settings. Several years later, Hirsch and his colleagues, using a modified form of the Howard-Dolman test, proved experimentally that the constant error varied systematically with the amount of the aniseikonia. Ripple and Wilson on the other hand, found no consistent relationship between aniseikonia measured on the Space-Eikonometer, and the constant error measured by a standard Howard-Dolman test. Subjects with large constant errors were, however, automatically excluded from the pre-selected group used in this study.

The chief purpose of the present study was to investigate the experimental conditions under which aniseikonia produces a constant error of the approximate amount predicted by theory.

*This work was supported by a contract between The Office of Naval Research and Johns Hopkins University.

Figure I illustrates the theoretical relationship between the percent of horizontal aniseikonia and the magnitude of the constant error. If the retinal image of the right eye is magnified by m percent, the apparent lateral separation of the rods will be increased from s , the actual separation, to $s + \frac{ms}{100}$. The right rod will

therefore appear further away than the left rod by a distance e which represents the constant error. By similar triangles $\frac{e}{e+d} = \frac{ms/100}{p}$. If e is small in comparison with the distance d , this reduces to $e = mds/100p$.

In this investigation, two types of moving-rod tests were used. The first was similar in most respects to the usual Howard-Dolman test. The fixed rod was at 6 meters from the subject, and the lateral separation of the rods was 67mm. The white background was illuminated to a brightness of approximately 15 ml. by means of two small lamps. The room was not otherwise illuminated. The light emerging from the open top and sides of the instrument was nevertheless sufficient to make dimly visible not only the front face of the instrument, but also other objects in the room. The position of the subject's head was kept constant by means of a chin rest, so that motion parallax could not furnish an auxiliary cue. The subject varied the distance of the movable rod by turning a wheel. Unpracticed observers find this method easier than the commonly used one in which the rod is moved forward or backward by pulling on the two cords, and the results are probably less dependent upon motor skill. (Howard's original procedure included the use of a chin rest and a pulley wheel adjustment. The final form of the instrument he recommended was, moreover, completely enclosed except for the front aperture).

In the second moving-rod test used in this study, two apertures close to the eyes were substituted for the single aperture near the rods. The right and left eye apertures differed in shape so that there were no fusible contours. These apertures effectively concealed from view not only the ends of the rods, but also all other objects in the room. With apertures close to the eyes, the rods must be much longer if their ends are to be outside the field of view. For convenience, therefore, in order to reduce the required rod length, in this test the fixed rod was located at 3 instead of at 6 meters. The lateral separation of the rods was 140 instead of 67mm. According to the formula $e = mds/100p$, the constant error produced by a given aniseikonia is directly proportioned to the distance and to the lateral separation. Since the distance of the rods was half as great in the second test and the lateral separation about twice as great, the predicted constant error is essentially the same for the 3-meter and 6-meter tests, i. e. about 65mm. for each one percent of aniseikonia.

Measurements were made of the position of apparent equidistance when afocal magnifying lenses of 0.9% and 1.9% were worn over the right and over the left eye. A single test-run comprised 10 adjustments of the movable rod. Five were made starting from positions at which it appeared definitely nearer than the fixed rod; the other five initial

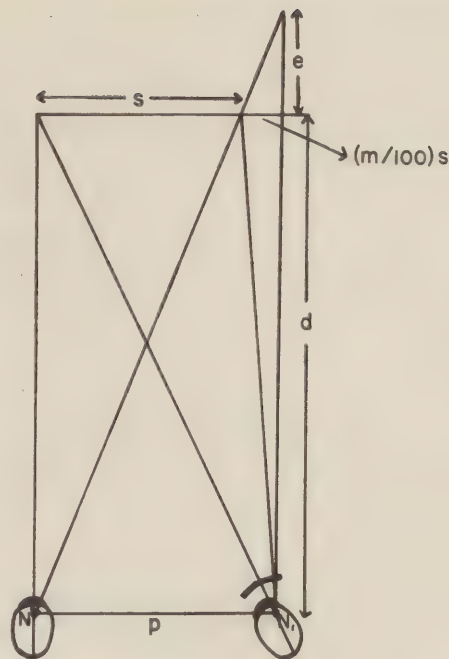


Figure 1.

$$\frac{e}{d+e} = \frac{(m/100)s}{p}$$

$$e = \frac{m d s}{100 p}$$

positions were such that it appeared definitely more distant. In the first series of experiments determinations were made for two subjects of the immediate effects of artificially produced aniseikonias on the constant error scores, referred to hereafter as CE scores. In these experiments each afocal magnifying lens was worn only during the actual tests. In the second series of experiments the effects of continuous wearing of such lenses for seven days or more were investigated.

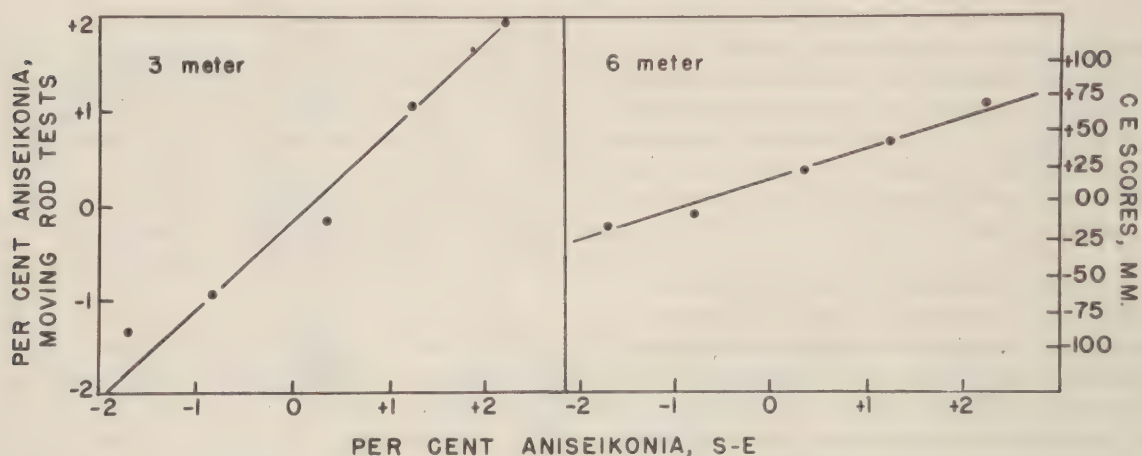


Figure 2A.

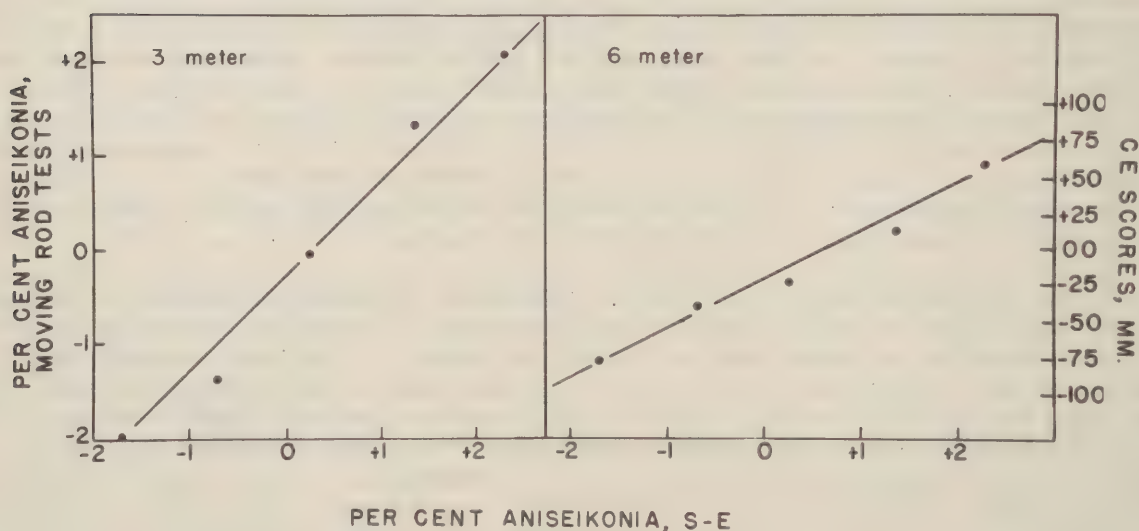


Figure 2B.

The aniseikonias in percent corresponding to each CE score in millimeters were computed from the formula, and these derived estimates of aniseikonia were compared with direct measures from the space eikonometer. In the graphs of Figure 2 the measured aniseikonic errors are shown on the horizontal ordinate, those computed from the CE scores on the vertical ordinate. (Errors corrected by magnification of the retinal image of the right eye are taken as positive). It is apparent that for both subjects and both tests there is an approximately linear relationship between the measured and computed aniseikonias.

For the data of the three-meter test, the best-fitting straight lines have slopes close to unity, indicating that the CE score on this test measures almost the full amount of the true aniseikonia. In the case of the six-meter test, the lines have slopes of 0.5 for one subject, 0.3 for the other. The CE scores therefore, reveal only a fraction of the aniseikonia created by the wearing of a magnifying lens. For subject L. S. for example, each one per cent difference in size of the retinal images in the horizontal meridian produces a constant error of about 20mm. instead of the theoretically expected error of about 65mm.

A possible explanation for the reduced sensitivity of the six-meter test pertains to the fact that overall lenses were used to produce the horizontal disparities. The so-called "induced effect" might therefore have decreased the CE scores. Ogle has shown that magnification in the vertical meridian can, under suitable conditions, also produce rotations of the apparent fronto-parallel plane. These rotations are in the opposite direction to those produced by horizontal magnifications. Further tests were therefore made, comparing the effects of overall and meridional magnifications. With an overall size lens of 1.9%, the apparent change in aniseikonia was 0.6%; with the same magnification, but in the horizontal meridian only, it was 0.9%. The actual change was, of course, 1.9% in both cases. The slight difference, i. e. 0.3%, in the two sets of measurements can be attributed to the induced effect. Since with horizontal magnification only (i. e. no induced effect), the 1.9% lens produced an apparent change of only 0.9%, some factor other than the induced effect must be primarily responsible for the reduced sensitivity of the 6-meter test to aniseikonic errors. The most probable explanation is that the perspective cues provided by the front face of the instrument and its oblong aperture, and by other visible objects, act in opposition to the cues provided by binocular disparity.

The purpose of the next series of experiments was to find out how effectively each of these tests measure aniseikonias that have been present for longer periods of time. Figure 3 shows the data for subject L. S., obtained during continuous wearing of a 0.9% lens before the left eye. In the right hand section of each graph the crosses show the day-to-day variation in aniseikonia during continuous wearing of the size lens. The circles at the left show, for comparison, five independent measures of aniseikonia obtained when the lens was worn only during the testing period. (These experiments were described in the previous section.) It is evident from the graph that, on the six-meter test, there was no significant difference in the aniseikonia associated with temporary and with continuous wearing of the size lens. On the other two tests the measured aniseikonias were perhaps slightly

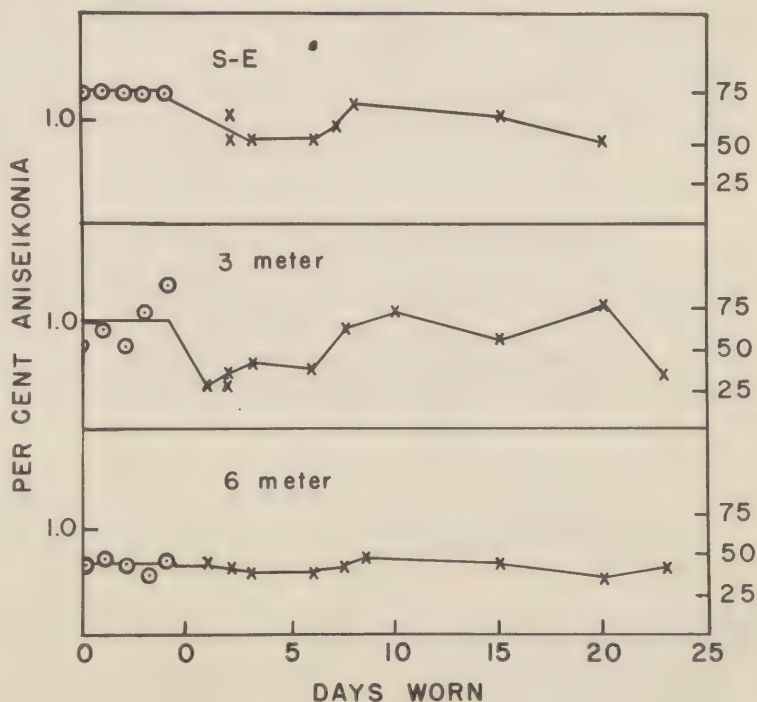


Figure 3.

less during continuous wearing of the lens. The measurements for the other three experimental conditions, namely with a 0.9% lens before the right eye and a 1.9% lens before the right and before the left eye, gave essentially similar results. The aniseikonias measured by the six-meter test were again not significantly different during temporary and

continuous wearing of the lens. Those measured by the other two tests were slightly less during continuous wearing.

Burian and Ogle noted a similar small decrease in aniseikonia after a few days of continuous wearing of a meridional size lens at axis 90° . They concluded that the decrease was not a true physiological change in the aniseikonia, but merely a psychological adaptation to the conflicting monocular depth cues present in ordinary surroundings. Our studies with overall size lenses indicate that in the Howard-Dolman test, where monocular cues are present in the test situation itself, this adaptation can occur immediately and may reduce the apparent aniseikonia to one-half or less of the true amount. On our three-meter test and on the space eikonometer the adaptation to an overall aniseikonia was, for our two subjects, of small magnitude, and was noted only after the size lens had been worn for one or more days.

Discussion

The results of this study indicate that the Howard-Dolman test of binocular depth perception is influenced, though in a somewhat unpredictable manner, by aniseikonic errors. The magnitude of the constant error associated with a given horizontal aniseikonia may for example differ significantly in different subjects. The CE scores moreover depend not only upon the horizontal aniseikonia, but may also be influenced by a difference in size of the ocular images in the vertical meridian. These scores are also affected by factors relating to the testing equipment, usually un-standardized, such as the amount of light falling on the front surface of the instrument and on other objects in the field of view. It has been suggested by Hirsch and Weymouth that the constant error score on a moving-rod test could be used to detect the presence and the approximate amount of aniseikonia. Our findings suggest, however, that if such a test is to give an adequate estimate of the horizontal aniseikonia approximating that measured by the space-eikonometer, then the only objects visible to both eyes must be the test rods themselves. However, even when this is achieved by the use of suitable apertures, the test does not detect all subjects having significant aniseikonic errors, because it measures only the horizontal component.

The following conclusions may be drawn from this study: (1) In order to distinguish between the two aspects of depth perception measured by the moving-rod type of test, the constant error in location of the movable rod should be distinguished from the variable error. (2) When the rods are separated laterally, the constant error score is related to the horizontal aniseikonia. This score does not, however, provide an adequate measure of the aniseikonia, unless all depth cues other than binocular disparity are eliminated.

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Discussion:

- Dr. Ogle asked if Dr. Sloan had ever tried using the method of constant stimulus in measuring space distortion at 6 meters. He stated that it is often found that at 6 meters there is less space distortion than one would expect.
- Dr. Sloan stated that she had not tried the method of constant stimulus, since the Howard-Dolman test is not going to be used that way. Parenthetically, Dr. Sloan commented that the Howard-Dolman test was used as a method of constant stimulus test by Howard. Dr. Sloan agreed that monocular cues to distance were important to the Howard-Dolman test in teaching the subject to evaluate his stereoscopic cues.
- Dr. Knoll commented that Dr. Sloan's data in which the time course of error was shown seemed to show an initial change and then a gradual return to the original value.
- Dr. Sloan agreed that the data seemed to show this.

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Dr. Blackwell reported experiments that he had conducted at the Polaroid Corporation in 1942. Measurements of the apparent frontal plane were made with two self-luminous reticles. These reticles were identical to the Howard-Dolman situation except that, being produced optically, there were no monocular cues present. Measurements under these circumstances were shown to be in good agreement with aniseikonia evaluated with the space eikonometer.

Dr. Berens asked if Dr. Sloan had used a greater aniseikonia than 2 percent.

Dr. Sloan answered that she had not, since she started out with the expectation that 2% aniseikonia would not be significant. She found, however, that she did not compensate the 2% aniseikonia as she had expected to do.

Dr. Berens then inquired if Dr. Sloan had experienced headaches when wearing the glasses.

Dr. Sloan assured him that she had absolutely no headaches.

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IRRADIATION AND STEREOSCOPY

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At the 28th meeting of the Armed Forces-National Research Council Vision Committee, the author presented a paper on the effect of retinal illumination on visual perception of space.¹ Since that time we have obtained additional conclusive data. This data is principally concerned with the relationship between brightness contrast and relative size of perceptive images. Furthermore, some revision of the original terminology seems to be indicated. Therefore, it might be beneficial to give a brief outline of the present status of this subject.

It may be recalled that a white square seen against a black background usually appears larger than a black square seen against a white background. In the case of apparent magnification of brighter areas at the expense of darker ones, Tschermak² speaks of positive irradiation. Under certain conditions just the opposite phenomenon occurs, that is, darker areas appear larger than brighter ones although they are objectively of equal size. Tschermak refers to such a case as negative irradiation. From these facts it can be inferred that a true image size-distance relationship rarely occurs since it occurs only if zero irradiation exists.

The irradiation mechanism as depicted in Figure 1 has been theoretically explained. If the eyes were entirely free of optical imperfections and oscillating movements, the light distribution over an illuminated retinal area would be box-like as indicated by the dashed outline. However, since the light is distributed in a rather ogive-like manner due to the optical defects of normal eyes and to oscillating movements, it can be assumed that the only light which can be perceived is the light exceeding threshold intensity. The perceptive image, therefore, differs markedly from the retinal image. In Figure 1, p_1 depicts the condition of positive irradiation, p_2 that of zero irradiation, and p_3 that of negative irradiation.

Experiments revealed that the irradiation effect depends on a great variety of factors which concern (1) physical properties of the incident light, (2) optical factors responsible for the formation of the retinal image, (3) physiological factors involved in the mechanism of the perceptive image formation, and last but not least, (4) psychological factors.

A method of measuring the apparent alteration of relatively large uniform surfaces has been described elsewhere.³ It is based on the phenomenon that relatively large con-

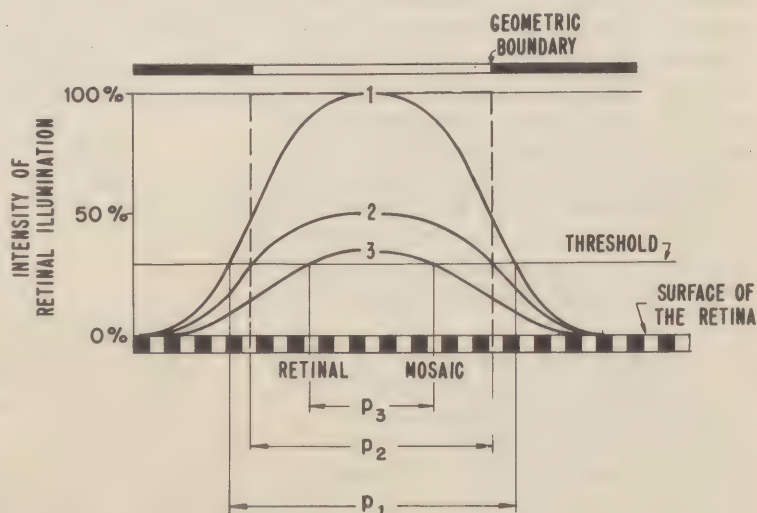


Figure 1. Schematic diagram of light distribution (solid curves) over the retina. (See Test.)

trasting surfaces (Figure 2) placed objectively in a frontoparallel plane apparently rotate about their respective central vertical axes when the retinal illumination of one eye is reduced by some means such as density filters or rotating sectors. By counteracting the actual planes, their apparent rotation can be offset. The irradiation effect can be measured from the angle of rotatory deflection at which the targets appear coplanar. Two surfaces have been used in our experiments.

Dr. Paul W. Miles,⁴ who is trying to apply this method to clinical cases, uses three uniform contrasting surfaces. Lately he has successfully applied a luminous grid of stripes every three inches on a black background. With this arrangement irradiation stereoscopy could be elicited within a range of 75 feet. Dr. Miles found that "irradiation stereoscopy" also exists spontaneously in persons with defective eyes.

As stated in the earlier paper, any difference in the function between the two eyes results in the spatial phenomenon which we at first termed "venetian blind effect" and later³ called "anisopic stereo-effect." Anisopia is defined in Dorland's Medical Dictionary as "inequality of vision in the two eyes." To avoid confusion with aniseikonia, Ogle⁵ proposed the term "irradiation stereoscopy," which I consider a very appropriate designation. In the future I shall use this term as a substitution for or synonymously with the term "anisopic stereo-effect."

Irradiation stereoscopy can be produced by neutral density filters, artificial pupils, stenopaic slits, rotating sectors, spherical and cylindrical lenses, or by different states of adaptation of the two eyes. The relationship between the differences in the light density and irradiation is shown in Figure 3. Here, δ represents the apparent contour shift as a function of the density difference (Δd) between the two eyes. The contrast in this test amounted to 35.

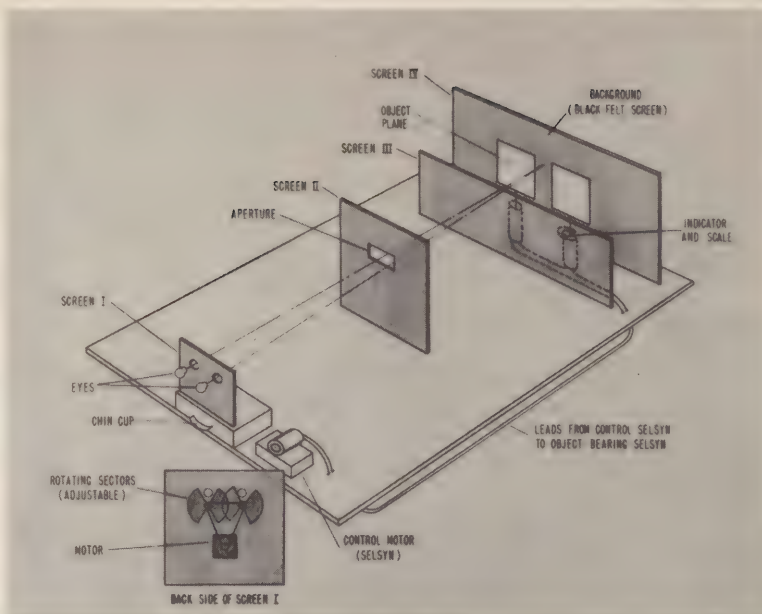


Figure 2. Scheme of arrangement of instruments used in the experiments.

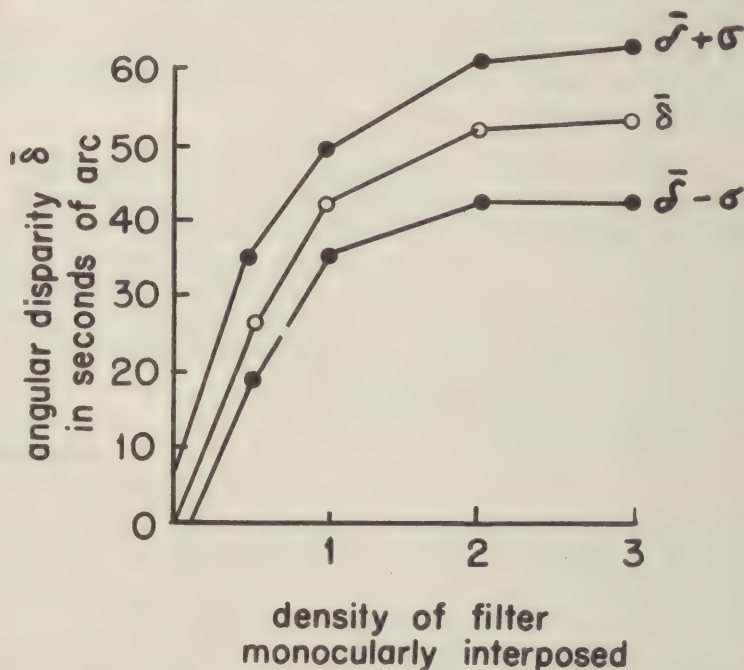


Figure 3. Mean (δ) of angular disparity and range ($\delta \pm \sigma$) of contour shift caused by density filters (abscissa) monocularly interposed. The data are computed from 460 measurements (23 subjects) over each point. Contrast $C_0 = (B_t - B_b)/B_b = 300$. B_t = brightness of target = 100 mL.

In the meantime it has been found that irradiation effects not only vary with the difference in illumination between the two eyes, but also with the contrast between the targets and the background. If the slope of the straight part of the curve in Figure 3 is designated $\Delta\bar{\delta}/\Delta d$, and plotted against the contrast, one obtains a curve which reveals a probably exponential relationship between "irradiation stereoscopy" and contrast.

Although our studies are far from complete, they bear some significance from both a theoretical and a practical standpoint:

1. They disclose strong evidence that the apparent position of contours in space and the apparent size of targets, as well as their apparent distance from the observer, are partially determined by the interrelationship between light distribution on the retina and the intensity thresholds of the sensory elements at a given state of adaptation.
2. Since atmospheric interference reduces the apparent contrast in accordance with Koschmieder's law, the data displayed may convey an idea of the amount of contour shifts and changes of the apparent size and distance of objects when they are seen through the contrast reducing atmosphere. This concept may be applicable to the contrast attenuation of optically homogeneous water.
3. Apparent spatial distortion caused by unequal illumination in the two eyes may lead to false judgment of situations and, consequently, errors in action.
4. The range of possible errors caused by irradiation stereoscopy lies between zero and sixty seconds of arc for each pertinent vertical contour.
5. The contour shift increases, probably exponentially, with the contrast and reaches a maximum at a contrast of about 55.
6. It is possible that the differences found in horopter determinations for bright and dark and for differently colored rods or wires are based on the contour shift responsible for irradiation stereoscopy. Further studies are needed.

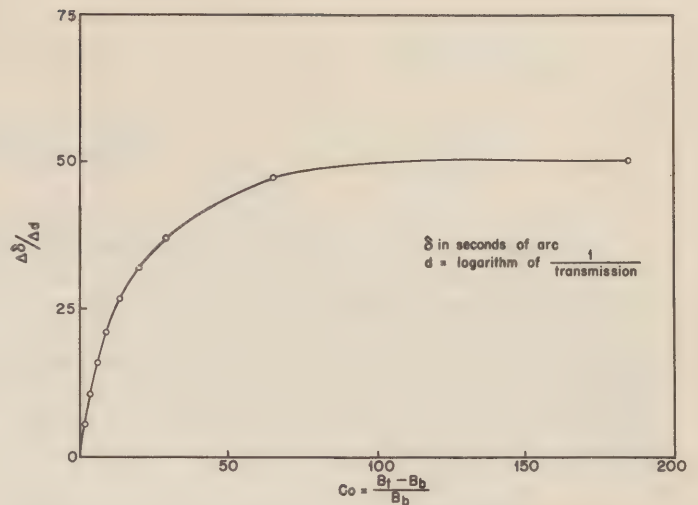


Figure 4. Variation of the slope $\Delta\bar{\delta}/\Delta d$ with the contrast between target and background. The computation is limited to an average pupillary distance of 66 mm., target side length of 160 mm., and an observation distance of 3m. Field brightness varying, target brightness constant (300 mL).

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Discussion:

Dr. Ogle congratulated Dr. Cibis on his discovery of the irradiation effect on stereoscopic vision.

Dr. Fry suggested that objects with blurred borders might well be used in this type of experiment. If one were to determine the spatial position of blurred objects with varying edge-gradients, one could establish the location in space of the effective border by the spatial localization of the blurred object.

PROTECTION AGAINST EYE DAMAGE FROM ATOMIC EXPLOSIONS

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When compared to a bomb with chemical explosive, the atomic bomb is characterized by penetrating ionizing radiation, by greater blast, and by a higher output of thermal radiation. The effective radius for those damages varies greatly (Table 1). The following discussion will be limited to a nominal atomic bomb equivalent to 20,000 tons trinitrotoluol. The effects of larger or smaller atomic bombs can be evaluated by using proper scaling laws.

Table 1

Effective Radius for Damage by a Nominal Atomic Bomb
Exploded in the Air on a Clear Day:

1	Lethal neutrons	2300 ft	38 acres
2	400 r initial radiation. (kills 50% of population)	4250 ft	130 acres
3	Severe blast 5.2 psi	6300 ft	290 acres
4	Incendiary action	6300 ft	290 acres
5	Moderate blast 2.7 psi	8800 ft	560 acres
6	Moderate skin burns	10000 ft	720 acres
7	Retinal burns beyond	20000 ft	2880 acres

Distances given under 1 through 6 according to reference (1).
1 r is 1 Roentgen unit.

Protection against ionizing radiation is necessary only in the inner parts of the effective circle of the atomic bomb. Since 600 r to 900 r (= Roentgen units) are the threshold for the formation of a radiation cataract (2) and 400 r on the whole body kills 50% of the population, it is evident that at distances from the atomic bomb, where the lens is endangered, shielding should protect the whole body. It can be provided by heavy metal and concrete structures. Protection against ionizing radiation is therefore not useful with eye protection devices alone.

Blast effects of the atomic bomb do not differ in quality from those experienced with chemical explosives in World War II. According to experience in air raids during World War II the main hazards to the eye from blast are glass particles and other building debris. Many injuries happened while persons walked down staircases with outside windows and during flight through streets when evacuation of a building was necessary during an air raid. Plastic goggles of 3 to 4 mm thickness have been shown to prevent most of this damage. Laminated or hardened glass lenses, though less effective, will prevent some damage by splinters too.

Thermal radiation is the hazard from the atomic bomb that has the widest effective radius. The damage of the skin is determined by the density of radiation which is pro-

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portional to the inverse square of the distance from the source. Moderate burns of the skin of the lids can be expected at 10,000 feet distance from a nominal atomic bomb. Visible and infrared radiation constitute the main part of the thermal radiation able to penetrate more than a few thousand feet. Only in the immediate vicinity of the atomic bomb, where ionizing radiation occurs in dangerous amounts, ultraviolet radiation constitutes a considerable part of thermal radiation. Some protection is given by dark goggles. Fair or dark complexion of the skin will affect burns of the lids. The skin of the lids is, due to folding and the protection from goggles, usually less dark than the rest of the skin when a person is suntanned. That diminishes the chances of a thermal radiation burn of the lids of a suntanned person. The more serious burns of the lids, occurring nearer to the explosion, should be considered as an immediate danger to the wounded who may be hindered during difficult flight through flaming streets filled with debris. The scarring of the lid tissue can lead to deformations of the lids, which might expose the cornea. Such deformations can only be repaired by lengthy treatment and plastic surgery. It seems to be worthwhile to try to avoid lid damage as far as possible. Two considerations might be helpful. First, the total thermal radiation is emitted during 3 seconds. Therefore, everybody who might conceivably be exposed to an atomic explosion, should train himself to start turning or spinning around his body immediately when a very bright flash of light appears. Spinning around is superior to turning from the supposed direction of the flash because it does not require the knowledge of the direction. While the body is spinning around, the radiation is spread over the whole circumference of the body. The density of radiation and with it the probability of a burn is much diminished. Second, at a depth of 0.1 mm in the skin and to a smaller degree down to 0.75 mm the build up of the temperature happens during 3 seconds to 12 seconds after the beginning of the explosion.⁽³⁾ The draining off of some of the heat energy is therefore promising. For the lids (and probably nose and mouth) it could be of great value for the prevention of burns to lay the hands on the skin of the face during the first 12 seconds after the beginning of the explosion. This beneficial effect is not based on covering during the irradiation but on draining away heat subsequently. A wet piece of cloth would do this better and could be kept ready for emergencies in a plastic pouch. Since the blast effects at distances where survival in the open is possible have some delay compared to the radiations, taking cover against blast should follow the above mentioned preventive measures.

While damage to the lids will be caused at distances comparable to those at which skin damage in general can be expected -- up to 10,000 feet -- the inner eye, especially its pigmented layers, retina, and choroid can be damaged at much greater distances. The reason for that is the focusing effect of the refracting media of the eye on visible and infrared radiations.

The radiation density in the image on the retina ϕ_{ret} is proportional to the density of radiation at the source of radiation and to the square of the relative opening of the image forming system. It is given by the following formula:

$$\phi_{\text{ret}} = \left(\frac{h}{b} \right)^2 \sigma T^4 f_0 f_1 f_2$$

where h is half the diameter of the pupil, b is the distance of the nodal point from the retina, h/b is the relative opening of the optics, T temperature of the radiation source in degrees Kelvin, σT^4 is the radiation density at the source, $f_0 f_1 f_2$ are attenuation factors which are conveniently subdivided as f_0 for pure air near the source, f_1 for long path through more or less polluted atmosphere, and f_2 for attenuation in the eye. f_0 depends on wave lengths and composition of the atmosphere and this is the reason for the cutoff of the radiation at 1860 Angstrom units. f_1 depends on wavelength and pollution of the air. For very clear air, visibility about 40 kilometers, $f_1 = e^{-\frac{0.1 \cdot a}{10^5}}$

(where a is distance in cm)

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f_2 is estimated for the eyes of younger people to be about 0.4. The energy density in the retinal images $\mathcal{U}_{\text{ret}}$ is given by the following formula:

$$\mathcal{U}_{\text{ret}} = \left(\frac{h}{b}\right)^2 \sigma \int_{t_0}^t f_0 f_1 f_2 T^4 dt$$

Neglecting the attenuation factor f_1 $\mathcal{U}_{\text{ret}}$ through a daylight pupil of 0.4 cm would be 33 gcal/cm² and through a night pupil of 0.8 cm would be 131 gcal/cm².

Due to the early peak in radiation from the atomic bomb more than 1/3 of the radiation hits the retina during the first millisecond (Fig. 1). Closure of the lids might be effected at best in 50 milliseconds, often more time will be used. At 6 Km distance in very clear air a younger man would have through a daylight pupil before closing the lids 2.2 gcal/cm². With a night pupil under otherwise equal conditions he would have 8.8 gcal/cm². Any delay in closing the lids would increase the amount of radiation hitting the retina.

If we designate the diameter of the fireball $2y$, the diameter of the image on the retina $2y'$, the distance of the fireball from the nodal point of the eye a and the distance of the nodal point from the retina b , then

$$y' = \frac{y \cdot b}{a}$$

b in the average eye is 1.729 cm, y at 10^{-4} sec is 1373 cm. Therefore at a distance of 20,000 ft or 6 km = 600,000 cm the initial fireball of 13,73 m radius forms geometrically an image of 0.04 mm radius or 0.08 mm diameter. That can cover a considerable part of the fovea. The real image would be slightly larger from the effects of scattering and diffraction.

The image size as well as the amount of irradiation are of practical consequence. Since data about minimum dosage for retinal burns are not available we can make an estimate by using data from skin burns. For white skin about 5 gcal/cm² for short time exposure are the minimum doses for burns. We can therefore assume that at about 6 km distance from the fireball in very clear air we can expect retinal burns from the nominal atomic bomb under daylight conditions, and that under night conditions this distance can be exceeded substantially.

For the first part of irradiation before lid closure occurs, a goggle seems best protection. Since this early radiation is mostly short in wavelength, a goggle transmitting only longer visible wavelength looks promising. For instance a red goggle with cutoff at 600 millimicron would cut down irradiation by more than 50%. Goggles would of course have to be chosen according to the visual tasks of the wearer.

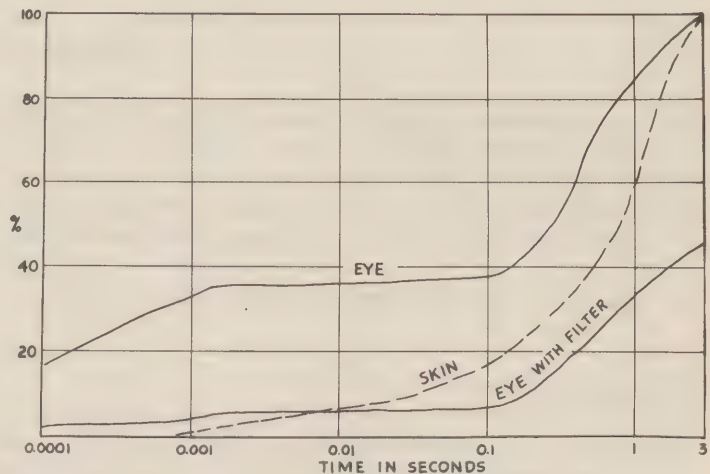


Figure 1. Percentage of the sum of radiation from a nominal atomic bomb, which has arrived at the end of each period of time on the skin, on the retina, and on the retina when a red filter has been used.

SUMMARY

1. The hazards to the eye from atomic bombs, ionizing radiation, blast, and thermal radiation are discussed. The special hazard to the retina from focused thermal radiation is pointed out.
2. Protective measures for the eye are described. They should become common knowledge for all physicians and be made known to the general population. Local protection alone of the eye against ionizing radiation is insufficient. Protection against debris scattered by the blast can be given by plastic goggles of 3 mm to 4 mm. thickness. The lids are protected by the brows and can be further protected by tinted goggles. The retina is protected by the reflective closing of the lids and can be further protected by filter goggles which cut off the ultraviolet and the shorter wavelengths of the visible light.

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Discussion:

- Mr. Stickle raised the question of whether the time it takes the eyelid to close would be radically changed with a filter because of the smaller stimulus to closure. Possibly with a filter the eye would take longer to close.
- Dr. Rose said that brought up the point of whether or not people will be trained to close their eyes when something overly bright happens. Even with a filter, an atomic flash will be very bright. The filter removes 50% of the radiation, but it is still bright. A darker filter would make it too dark for the wearer to see on the streets, making walking or driving impossible.
- Mr. Stickle remarked that there is a great deal of difference between reflex action and action when the eye is trained.
- Dr. Rose felt that the general population ought to have some such training if they are going to be exposed to atomic radiation.
- Dr. Berens asked if the damage to the retina was due to radiation or to general sereological effects upon the body which indirectly affected the retina.
- Dr. Rose stated that the damage was due directly to heat effect on the retina.
- Col. Byrnes explained that Dr. Rose was speaking of thermal radiation.
- Dr. Rose added that the damage would not be due to any specific effect but simply to pure energy--too much in one small place. He cited an instance where an eye exploded under too much heat.

~~RESTRICTED~~

CHANGES IN VISUAL FUNCTION AS A RESULT OF GRAVITATIONAL STRESS

PART I Visual Acuity in Prone Body Position

William J. White
Aero Medical Laboratory
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Current emphasis in aviation upon high performance jet and rocket propelled aircraft have increased the significance of gravitational forces "g". Comparatively few studies have been undertaken on gravitational stress and its effect on visual functions. It is the purpose of this paper to report on the first in a series of studies designed to describe the changes in human visual acuity resulting from increased gravitational forces while in various body positions. This study is concerned with the prone body position.

Apparatus

The Aero Medical Laboratory human centrifuge was used in this study. The centrifuge produces gravity forces in exactly the same manner as does a turning aircraft. A rotating boom carries a bed carriage around in a horizontal circle. The carriage is free to pivot on a horizontal axis tangent to the circle of rotation of the boom. As the speed of rotation of the boom increases, the gravity forces increase and the bottom of the cab swings outward and upward toward the horizontal. Thus the g force is approximately transverse to the long axis of the body.

Visual acuity was tested using the Bausch and Lomb Ortho-Rater with the standard slides provided with the instrument. Near and far acuity tests were used for both binocular and monocular eye tests. The occluder was not used during any of the experimental runs. Two external modifications were made to the instrument; one of these enabled the safety observer to position the slides or the viewing box according to a prearranged schedule while the second was a support for the head of the subject. Figure 1 shows a side view of the experimental situation with the subject in position for testing.

Subjects

Five male subjects were used in this study. Their ages were between 23 and 28. Since there are many factors incident to riding the centrifuge other than a simple increase in gravity, only those persons with considerable centrifuge experience were selected as subjects. All subjects were given a complete ocular evaluation which consisted in part of cycloplegic and manifest refractions. The results of the examination showed that all subjects were free from ocular diseases and had an unaided visual acuity of 1.0 or better.

Test Procedure

The test procedure in this study differed in several important respects from that recommended in the Ortho-Rater manual:

1. The subject's body was in the prone position as compared with the instruction,
- ~~RESTRICTED~~

"...the subject will be seated comfortably..." The instrument and the subject were positioned so that the line of visual regard was approximately parallel to the force of gravity.

2. Each individual score was determined by the last item read correctly before the first error was made. This is in contrast to the recommended scoring "...answers incorrectly...two items in succession." Preliminary studies supported the observation made by Dr. L. L. Sloan that the conventional method of scoring overestimates the acuity of many subjects.

3. Neither the standard presentation sequence nor the recommended test questions were used. There was complete counterbalance between the near and distant acuity conditions. The acuity test sequence of binocular-right eye-left eye was always used.

The day prior to the first experimental ride on the centrifuge the subjects were individually indoctrinated concerning the test procedure and given a practice "ride" under 1 g conditions.

During the indoctrination the subjects were shown a photograph of one of the slides and were instructed as to what they might expect to see in the Ortho-Rater. The subject was informed that when riding the centrifuge it would be their task to report the location of as many of the checkerboards as possible.

Following this indoctrination the subject was given a practice session which duplicated the conditions of the experiment in every respect except that the centrifuge was not moving. After the subject had positioned himself on the bed, adjustments were made to the foot rests and test apparatus so that the subject was looking through the center of the lenses in the instrument. The experimenter assumed his position in the control room and made a check of the two-way communications system. A few seconds after the room lights were turned off it was announced to the subject that terminal g had been reached (which in the case of this practice session was one) and that the subject was to start reading. The experimenter recorded each response as it came over the loudspeaker as correct or incorrect according to the key supplied with the Ortho-Rater. After finishing the three acuity tests the subject was told that he was being "brought down." After a ten minute rest period he was returned to g conditions for further testing under conditions of far or near acuity as the schedule required. On being "brought down" for the second time and after a ten minute rest period another test of visual acuity was made.

On the day following the indoctrination session and practice run the instructions were repeated in an abbreviated form for the actual experiment, and the subjects appeared to understand their part of the task. The subjects were not informed of the gravity conditions they would experience while participating in the study. Neither were the subjects told of their scores at the various gravity levels nor how they compared with each other.

The sequence of gravity conditions used in this experiment was: 1, 6, 2, 4 and 8. These gravity values are well within the limits of human body comfort and safe tolerance in the prone position. To minimize any fatigue or practice effect, a period of approximately five days separated an individual's run under increased gravity conditions. The experimental runs between 1 and 6 g were of approximately 4 1/2 minutes duration while the 8 g run lasted for about 2 minutes. The duration of the 8 g run was made shorter than the other gravity runs since the head rest was too uncomfortable for longer periods of time. With this reduction in time it was only possible to test near and far binocular acuity.

Results

In the following report of results all acuity values are expressed as means of individual subject's scores. All values are expressed in decimal notations. Each individual's acuity score was determined by the last item read correctly before the first error was made.



Figure 1. Side View of the Experimental Situation With The Subject in Position for Testing.

Analysis of the data reveals a systematic change in visual acuity as a function of increased gravitational forces. Figure 2 shows a graph of the mean binocular acuity scores plotted against the gravity forces used in this experiment. Notice that the broken line connects those points that comprise the near acuity function, while the solid is the distance acuity function. At 1 g the distance acuity is 1.15 and the near acuity is 1.09. It should be pointed out that these values are the results of pooling data obtained at two different times. Scores were obtained at 1 g as part of the sequence of gravity conditions; moreover, acuity scores were obtained at 1 g conditions immediately following each experimental run. An analysis was made of the scores obtained at these different times and the differences were found to be insignificant. It is for this reason that these data were pooled.

At 2 gravity units, there is a reversal of the near and distance acuity scores, and this reversal is consistent through the 8 g condition. At the present time it is not possible to say if the separation of the acuity values under these conditions is statistically significant. The separation between these two functions at 6 g (0.64 and 0.78) may be in part due to the fact that it was the first experimental run under gravitational stress. However, the functions under monocular acuity conditions also show this separation.

The final points shown on the graph are: Near acuity 0.56, far acuity 0.54. If we consider the visual angle subtended by the last correct item reported under the 8 g conditions as 1.8 minutes of arc and the visual angle of the last correct item under conditions of 1 g as 0.91 minutes of arc then there is approximately 50% loss of visual acuity under conditions of 8 g and prone body position.

Figure 3 shows a graph of mean monocular visual acuity for the right eye. There is almost point to point correspondence between this graph at 1, 2 and 6 g and the preceding binocular data. No monocular acuity measurements were made under the 8 g conditions. The monocular acuity scores at 4 g are higher than those obtained when testing for binocular acuity.

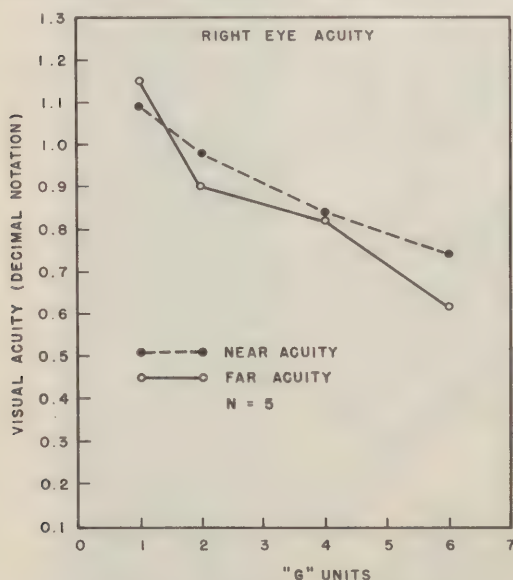


Figure 3. Mean Acuity Scores for Right Eye at Each Gravity Condition.

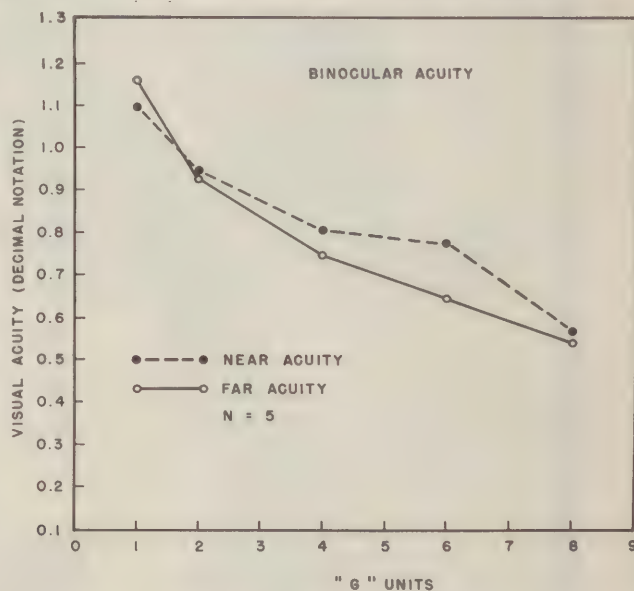


Figure 2. Mean Binocular Acuity Scores at Each Gravity Condition.

Figure 4 shows a graph of mean visual acuity for the left eye. When compared with the binocular data there is almost point to point correspondence between the distance acuity functions except for the 1 g condition. The near, monocular acuity function has a different slope than its counterpart on the binocular graph.

In summary, the results of this study indicate (1) that there is a systematic degradation in both binocu-

lar and monocular visual acuity as gravitational force is increased beyond 1 g, (2) that far acuity appears to be affected more by gravitational stress than does near acuity, (3) that there is a difference between near and far visual acuity scores under conditions of 6 g and this difference is consistent in both the binocular and monocular data.

Discussion

An examination of these data suggests several hypotheses on why this change in acuity occurs under gravitational stress. The three hypotheses listed below are not intended to be either mutually exclusive or exhaustive and it is intended that these and other hypotheses will be discussed in some detail in a future paper.

1. Displacement of the Lens in the Direction of Increased Gravity.

If the lens is displaced in the direction of gravity, and if the degree of accommodation is at the near point or slightly beyond, the blurring of the retinal image can be corrected by decreasing accommodation. However, if the non-hypermetropic eye is unaccommodated and the crystalline lens is displaced in the direction of gravity, it would not be possible to focus the retinal image sharply by changes in the accommodative apparatus. From this hypothesis the prediction would be that near acuity would not be affected by increased gravitational stress while far acuity would become progressively poorer with increasing g force.

2. Changes in the Shape of the Eye Ball.

If the increase in gravity caused the posterior pole of the eye to flatten, the eye would become effectively hypermetropic and this refractive error could be compensated by accommodation. However, if the mechanical forces resulting from increased g should aspherically deform the refracting surfaces of the cornea or the lens, a decrease in both far and near acuity would be expected.

3. Deterioration of the Physiological Image due to Local Ischemia and Pressure.

Physiological studies of cerebral blood pressure as a function of increased gravity and prone body position show that there is a slight drop in pressure, but no gross changes in vision have been reported under these conditions.

Discussion:

Dr. Knoll inquired about the general discomfort to the individual during Lt. White's gravitational experiments.

Lt. White described the equipment and the subject's position. Since the head under 1 G conditions weighs about 12 pounds and under 8 G it weighs eight times that, a mask is needed to support the head. The head mask is fitted down to the cheek bone, but kept away from the soft tissue of the eye. In order to simulate the pressure produced by gravitational stress, they had someone sit on the subject's head and then tested his acuity. However, according to Lt. White, the subject was not really suffering but was, in fact, fairly comfortable.

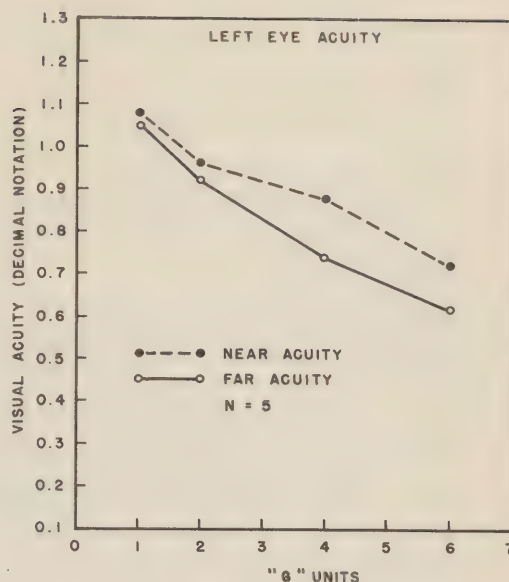


Figure 4. Mean Acuity Scores for Left Eye at Each Gravity Condition.

- Dr. Knoll wondered if there was any indication from other physiological studies that the sympathetic nervous system might be overstimulated.
- Lt. White noted that these men were experienced centrifuge riders and doubted that there were sympathetic nervous system effects.
- Dr. Knoll thought that it would be interesting to perform color vision tests under centrifugal conditions and remarked that he believed someone had done this with the subject lying on his side. When the blood drains out of the eye, differences in color vision can be expected.
- Lt. White said this had been tried under 6 G conditions. One color blind person was tested, then "cranked up" to 6 G and measured again; there was no improvement.
- Group Capt. McCulloch asked if Lt. White had experimented with subjects lying on their backs.
- Lt. White said he had not, but was planning studies with the subjects in various positions.
- Dr. Allen thought it would be interesting to study the effects of gravity on accommodation generally, though no simple relations would be expected, since both near and far acuity are involved. He then asked if Lt. White had run any test on the total accommodative amplitude.
- Lt. White answered that they had not, for this was primarily an exploratory study, but they planned to make an extensive study later on.
- Col. Byrnes suggested that the general disorientation effects of G stresses could affect accuracy even for experienced centrifuge riders.

GLAUCOMA DETECTION PROGRAM AT WRIGHT-PATTERSON AIR FORCE BASE

by Major John A. Buesseler, USAF (MC)*
Andrew C. Andrews, M. D. **
Brig. Gen. Otis B. Schreuder, USAF (MC)***

GLAUCOMA AS A NATIONAL PROBLEM

It is the opinion of most ophthalmologists as well as of the Ophthalmologic Foundation of New York, that glaucoma is the principal cause of blindness in the United States. It's victims make up 12% of the 160,000 totally blind persons in this country or an aggregate of 31,000 Americans. Each year 2,600 more persons lose their sight from this disease. (1) (Figure No. 1)

A survey of 10,500 adult industrial workers over the age of forty (40) years made by the Philadelphia Committee for Prevention of Blindness revealed that 280 persons, or 2.7% of the total group, possessed previously undiagnosed ocular hypertension. Only 4 of the entire 10,500 workers knew that they had glaucoma. (Figure No. 2). On the basis of these figures, it is estimated that approximately one million adult Americans have glaucoma and do not know it. (2)

GLAUCOMA DETECTION IN THE UNITED STATES

Because blindness from glaucoma can usually be prevented or arrested by early diagnosis and treatment, the problem with which we are most concerned is principally one of early glaucoma detection. In this regard, "wide angle" or so-called chronic simple glaucoma possesses the most subtle of signs and symptoms which make its early detection a major public health problem. There is no pain or visual disability in the early stages of this disease. However, an increase in ocular tension, most frequently of only a relatively mild degree above normal, is a measurable early sign. It is upon this sign that early detection is primarily based.

OPHTHALMOLOGIC FOUNDATION REPORT

	<i>No. of persons</i>
★ Total blindness in the United States	160,000
★ Total blindness due to glaucoma	31,000
★ Annual increase in blindness due to glaucoma	2,600

Figure 1.

PHILADELPHIA COMMITTEE for prevention of blindness

(SURVEY OF ADULT INDUSTRIAL WORKERS)

	<i>No. of persons</i>
★ Total group tested (over age 40 yrs)	10 500
★ Portion of group possessing ocular hypertension	280
★ Portion of group with previously known glaucoma	4

Figure 2.

*Chief, Eye Service, USAF Hospital, Wright-Patterson Air Force Base, Ohio
**Director, Preventive and Occupational Health Service Branch, Wright-Patterson Air Force Base, Ohio
***Air Surgeon, Air Materiel Command, Wright-Patterson Air Force Base, Ohio

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Unfortunately, the instrumental measurement of ocular tension as a routine part of an examination has in the past been delegated almost completely to the Ophthalmologist. He has, therefore, borne the major burden for glaucoma detection and, to him, the disease has long been a source of concern, largely because its victims reach the eye physician frequently after far advanced and irreversible damage has been done to the visual apparatus.

To prevent these often repeated tragedies of late diagnosis in glaucoma, the Ophthalmologic Foundation of New York with the energetic guidance and assistance of Dr. Conrad Berens, has launched a plan for the prevention of blindness from glaucoma through cooperation between Ophthalmologists and other physicians. The program is based on dissemination of information and organization of intra-professional teamwork in glaucoma detection, under the supervision of Ophthalmologists through the auspices of their respective county medical societies. Intra-professional cooperation is essential because General Practitioners and other physicians see probably 100 times as many patients as do Ophthalmologists.⁽¹⁾ Their opportunity to detect elevated ocular tension is therefore proportionately greater.

As an aid in facilitating the screening of patients for possible ocular hypertension, the Ophthalmologic Foundation has developed the Berens-Tolman Ocular Hypertension Indicator.⁽¹⁾ (Figure No. 3.) This relatively sturdy and inexpensive plastic and metal instrument can be carried in a doctor's pocket or medical bag for ready availability on the occasion of any examination. It is the incorporation of ocular tension determinations into the physicians' routine for physical examination which is most desired and necessary for early glaucoma detection. For this screening purpose, the Berens-Tolman Ocular Hypertension Indicator is designed for direct reading to indicate simply whether the ocular tension is low, normal, or high, and, if high, whether it has reached any emergency stage.⁽¹⁾ (Figures 4 and 5.) Prompt referral of any suspected cases to an Ophthalmologist is the completing link in the intra-professional detection program.

GLAUCOMA DETECTION IN THE AIR MATERIEL COMMAND

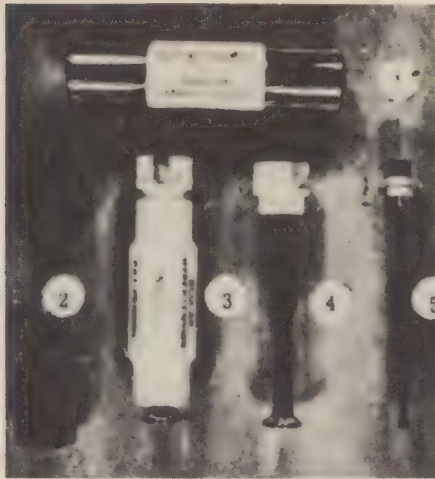
In view of the great significance of blindness to the individual working man as well as to the national welfare, it is only natural that Industrial Medicine concern itself with the glaucoma problem. The Air Materiel Command is in many ways similar to a large industry, and, as such, has progressively developed and improved the preventive and occupational health services for its civilian employees. Besides having placed special emphasis on the early diagnosis of such disorders as diabetes and hypertension, the Command has directed particular consideration toward the industrial eye care program. As evidence of some of the progress made in this field since the last Air Materiel Command report given at the 29th meeting of this committee in November of 1951, the Orthorater has become universally used for vision testing in the pre-employment and the five-year multi-phasic physical examinations. In addition, the Command has instituted illumination studies and the establishment of illumination standards for specific job requirements and work areas.

Recently, a plan for glaucoma detection was added to the eye care program. Its significance may be gathered from the fact that the Air Materiel Command currently employs approximately 170,000 civilian workers. Of these approximately 25,000 are situated at Wright-Patterson Air Force Base. It is estimated that the employees in these groups over the age of 40 years number approximately 71,000 and 10,500 respectively. On the basis of previously mentioned statistics (2), 2.7% of these groups or 1,928 persons in the Air Materiel Command and 280 persons at Wright-Patterson Air Force Base presumably possess undiagnosed ocular hypertension. (Figure No. 6.)

The Ophthalmologic Foundation's screening program for glaucoma detection⁽¹⁾ was considered to be outstandingly well suited for adaptation to the industrial medical facilities and functions of this military establishment. The testing program has thus far been limited

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OCULAR HYPERTENSION INDICATOR



1. Instrument with caps in place protecting moving parts. Total length 7 cms.
2. Protective caps.
3. Caps removed. Ready to use.
4. Foot plate assembly. 12.0 gms.
5. Plunger assembly. 5.5 gms.

Ophthalmological Foundation Inc.
Glaucoma Project.

THE OPHTHALMOLOGICAL FOUNDATION
314 E. 14th Street, N.Y.3., N.Y.C.
GLAUCOMA PROJECT

Figure 3.

THE OPHTHALMOLOGICAL FOUNDATION, INC.
Dedicated to the Conservation of Sight

314 EAST FOURTEENTH STREET GRAMERCY 7-3546 NEW YORK 3, NEW YORK

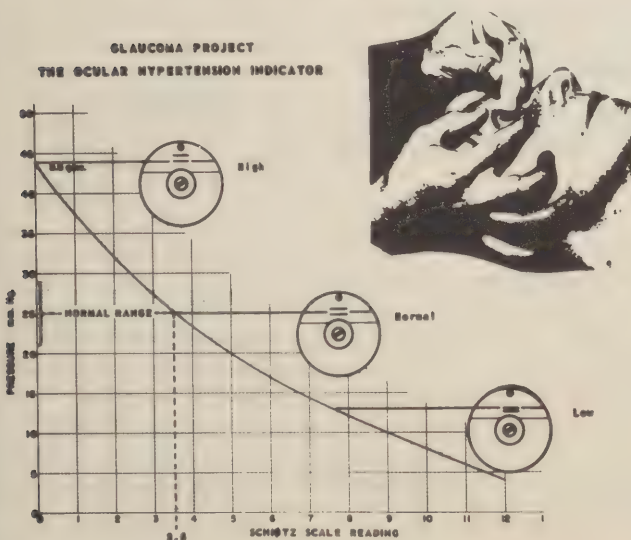


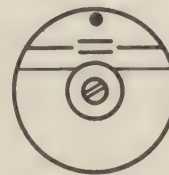
Figure 4.

READING THE HYPERTENSION INDICATOR

Low

Normal

High



Scale 7.5
mmHg 13.0

3.6 0.0
25.0 44.0
THE OPHTHALMOLOGICAL FOUNDATION
314 E. 14th Street, N.Y.3., N.Y.C.
GLAUCOMA PROJECT

Figure 5.

to Wright-Patterson Air Force Base in order to determine its most effective means of application before extending the plan as standard procedure to the remaining portions of the Command.

At this base, the screening of civilian employees for glaucoma is conducted by the civilian physicians of the Preventive and Occupational Health Services Dispensary using the Berens-Tolman Ocular Hypertension Indicator. The testing is incorporated into the routine of the pre-employment and five-year multi-phasic physical examinations of persons over forty (40) years of age. In addition, a check list of present employees over the age of forty (40) years has been made, and these individuals are currently being called in alphabetical order in small groups of six (6) or eight (8) each day for testing with the Berens-Tolman Ocular Hypertension Indicator. Although the program is still in its infancy at this installation, seven (7) cases, or 2.9%, of abnormally elevated ocular tension have already been found among a total of 238 persons tested over forty (40) years of age. (Figure No. 7.) To date, only five (5) persons have refused to undergo the simple test.

A M C GLAUCOMA ESTIMATE

	<i>No. of persons</i>
★ Civilian employees of AMC	170,000
Civilian employees at WPAFB.....	25,000
★ A. Employees over age 40 yrs in AMC	71,000
★ B. Employees over age 40 yrs at WPAFB...	10,500
★ Estimated cases of undiagnosed ocular hypertension in Group A....	1,928
★ Estimated cases of undiagnosed ocular hypertension in Group B....	280

Figure 6.

GLAUCOMA DETECTION AT WPAFB

(PRELIMINARY REPORT)

	<i>No. of persons</i>
★ Group tested	238
(over 40 yr. age)	
★ Portion of group possessing ocular hypertension	7
<i>Percentage of</i> GROUP POSSESSING OCULAR HYPERTENSION	
	▶ 2.9%

Figure 7.

Each person found to have ocular hypertension is informed of the findings in his case and advised of the importance of obtaining further evaluation and care from an Ophthalmologist as soon as possible. To facilitate the transfer of the case to an Ophthalmologist and to allow the employee a free choice of physicians, the individual concerned is given a list of all the diplomates of the American Board of Ophthalmology who conduct practice within a reasonable driving distance of this Air Base. The employee is urged to select any one of the listed Ophthalmologists and is given a form letter of introduction which explains to the Ophthalmologist the purpose of the patient's visit and requests that an abstract of the ocular evaluation be returned to the Preventive and Occupational Health Services Office of Wright-Patterson Air Force Base. (Figure No. 8.)

It is hoped that as the survey progresses, not only at Wright-Patterson Air Force Base, but also in the rest of the installations of the Air Materiel Command, enough data

will be accumulated to be of statistical significance in further evaluating the problem of asymptomatic glaucoma and glaucoma detection.

SUMMARY

A brief statistical review of glaucoma as a cause of blindness in the United States and of ocular hypertension as an asymptomatic finding in persons over forty (40) years of age, has been presented.

The program for intra-professional cooperation in glaucoma detection and the Berens-Tolman Ocular Hypertension Indicator as sponsored and developed by the Ophthalmologic Foundation of New York was described in basic principle. An adaptation of the Ophthalmologic Foundation's glaucoma screening program for use by the Preventive and Occupational Health Services of the Air Materiel Command, and at present being utilized at Wright-Patterson Air Force Base, was introduced and a preliminary report of initial data presented.

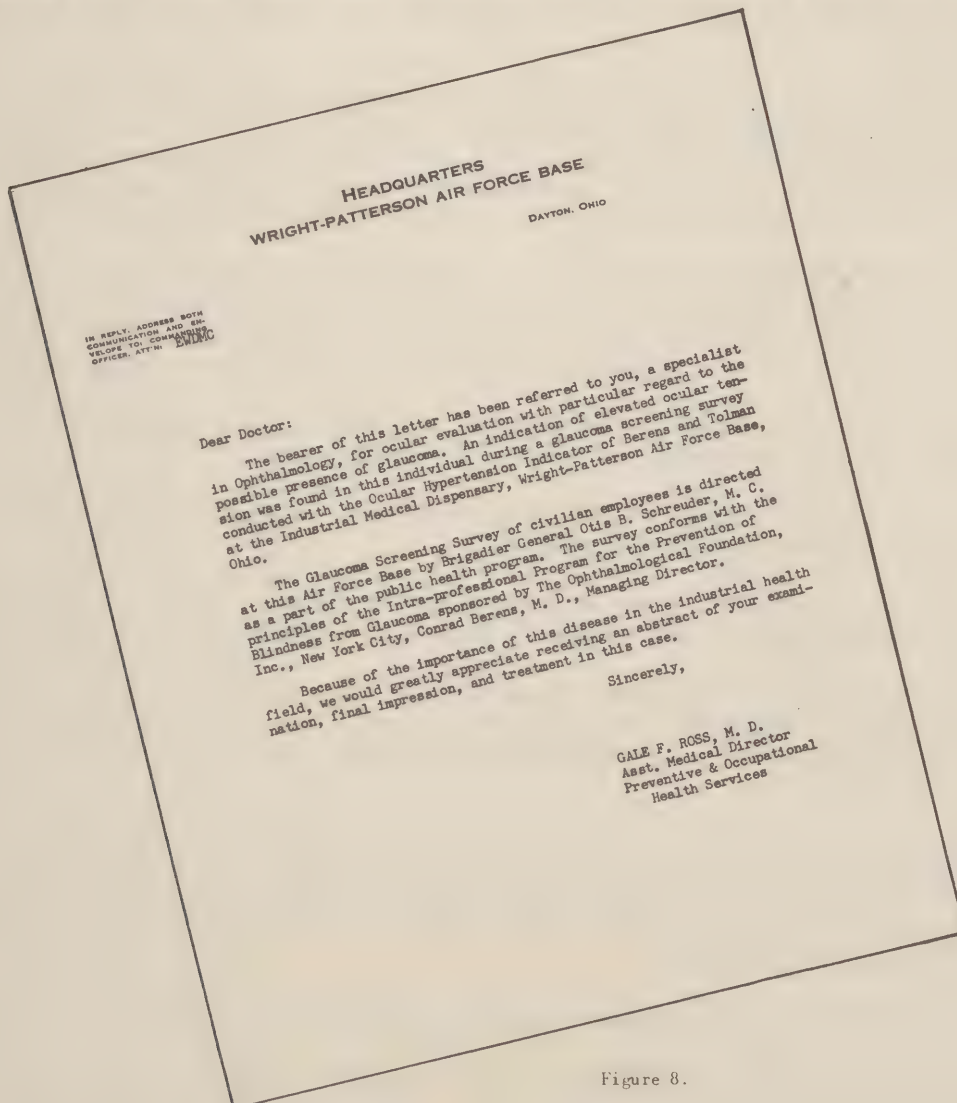


Figure 8.

- (1) Prevention of Blindness through Research, Teaching and Clinical Studies on an Intra-Professional Level (pamphlet), Conrad Berens, Ophthalmologic Foundation, Inc., New York, New York.
- (2) Prevention of Blindness from Glaucoma, Conrad Berens and Charles P. Tolman, Acta Ophthalmologicum, XVI, Concilium (Britannia), 1950.

Discussion:

- Dr. Berens was very much in accord with all that Maj. Buesseler said about the need for making headway against glaucoma, which accounts for at least 12% of blindness. He stressed the need for a testing instrument that can be easily used. He commended Gen. Schreuder and Maj. Buesseler for their outstanding work, and noted with interest that they had discovered just about the same percentage of cases of glaucoma as had been found by his group in Philadelphia.
- Dr. Sloan requested that Dr. Berens tell the Committee something about the Berens-Tolman instrument.
- Dr. Berens said that their aim was to develop an instrument that could be easily used. Even if some of the older physicians in practice would not use it, they felt it could be introduced in the medical schools and thus to the younger practitioners. It was their opinion that the instrument should be kept in the hands of people who would know how to use it, so as to avoid mistakes which would prejudice people against the instrument.
- Dr. Berens described the instrument as a cigar-shaped affair about 2" long, similar to the Schiøtz, but without the big indicating scale. The outside is a plastic tube and there is a plunger inside. If the eyeball is hard and the plunger does not go as deep, the indicator line goes higher. A red dot is now used. This serves as a danger signal.
- Dr. Knoll asked if he was correct in his understanding that Maj. Buesseler had found that 2.9% of the over-40 age group had excessive hypertension.
- Maj. Buesseler replied by saying that 238 people--all over 40 years of age--were tested. 2.9% of those tested had elevated tension.
- Dr. Knoll referred to statements made by Duke-Elder that field changes actually precede changes in ocular tension. He wished to know why fields were not measured.
- Maj. Buesseler explained the difficulties of getting field measurements. He noted that his group deals with civilian employees and had to try to work out this program with civilian ophthalmologists. Few ophthalmologists were willing to make the necessary field measurements.
- Dr. Kuhn made the point that there is no such thing as a reliable field of vision test for mass production, and that this is what has thus far made it impractical to do fields en masse, in industry, for example. She enthusiastically welcomed the Berens-Tolman instrument as a first step and hoped that eventually a field gadget could be developed to pick up cases of glaucoma.
- Dr. Wolpaw was interested to learn how many false positives were obtained.
- Maj. Buesseler said they had checked their results with the Schiøtz meter and had found only one false positive in the seven positive cases. That is, only one person was found to have abnormal tension with the Schiøtz after being checked by the Berens-Tolman.

Dr. Wolpaw asked if that meant that only 6 of these patients had glaucoma.

Maj. Buessler explained that elevated tension does not necessarily mean the patient actually has glaucoma, but is only an indication of glaucoma. Whether the patient actually has glaucoma or not must be determined by further study.

Dr. Wolpaw commented on the difficulties arising out of false positives, saying that patients later cannot be convinced that they do not have glaucoma, or syphilis, or whatever the disease may be.

Maj. Buessler agreed that this was a real problem and not one to be minimized. For that reason, he said, civilian physicians at the Air Materiel Command dispensary are extremely careful in informing patients of their findings. They tell them that further evaluation is necessary before any final diagnosis can be made.

PROBLEMS OF THE USE OF CORRECTIVE LENSES AND FILTERS WITH OXYGEN MASKS

Colonel J. H. Bristow
and 2d Lt. Donald G. Pitts,
Nellis Air Force Base

The purpose of this paper is to present a few of the visual problems which occur among the pilots of jet fighter aircraft. A solution will be offered in certain of these problems although it is conceded that there are other solutions and probably better ones.

Due to the fact that the mission of Nellis Air Force Base is such that a great number of trained pilots are constantly passing through on a ten-week TDY status, we encounter a small number of pilots who must wear corrective lenses in order to obtain at least 20/20 vision, each eye. With the present acute need for young fighter pilots it is quite necessary that these bespectacled people be furnished glasses which they can wear while operating the aircraft. The use of spectacles by pilots of propeller-driven aircraft flying at ten thousand feet and below presents no great problem. The standard issue frame and the standard issue sun glasses frame are quite adequate inasmuch as they are able to be fitted to the pilot's face so that his field of vision is not obstructed and the optical axis of the lenses can easily be made to conform to the interpupillary distance of the individual pilot. When the bespectacled pilot steps into the cockpit of a jet aircraft, an entirely different situation exists as far as his glasses are concerned. He must secure his oxygen mask and have his glasses on his face in such a manner that they will be permanently adjusted without further attention to them until he touches down. He has no time for re-adjustment of any of his gear once he is airborne.

A number of attempts have been made by individual pilots to wear the ordinary metal type of issue glasses, as well as the plastic frame type, behind the oxygen mask. This is never satisfactory due to the mask fitting over the bridge of the nose so closely that the spectacle frame is pushed back to a point where the lashes rub on the lenses, resulting in an annoyance to the pilot as well as smearing the lenses. The next alternative was to wear the spectacles over the oxygen mask, allowing the frame of the spectacles to rest on the mask rather than on the nose. This was immediately found to be impracticable as is illustrated by this first photo showing the issue plastic spectacle riding much too high so that the pilot was looking through the lower one-third of the lenses. It was also evident that the heavy plastic frame is not suitable because of the fact that it obstructs the pilot's view when he looks near the edge of his spectacles.

The next photo shows the ordinary issue sun glasses frame in place. While this is an improvement over the plastic frame, inasmuch as it allows the pilot a larger lens and also a narrow frame, it is readily seen that this is impractical due to the fact that it rides much too high while resting on the mask. On this particular slide the pilot's head is tilted just a little too high, which exaggerates the point I have just made, but we have found that this frame does not prove satisfactory. It is to be particularly noted here that the distance between lenses is not as great a factor in making this frame unsuitable for use with the oxygen mask as the shape of the lenses. Were the lenses so shaped that the nasal portion of the frame was more cut away it would allow the frame to rest on the mask in such a manner that the pilot would be using the larger portion of the lens in all aspects of gaze rather than just the lower one-third. Authorization was given our Base to have the Alameda Medical Depot make up a few frames which had a cut-away nasal portion of the lenses and a fairly wide DBL. The solution to the problem was found to be very simple because by using the Bausch & Lomb sun glasses frame, with a seventeen-millimeter distance between lenses, all pilots were able to be fitted very satisfactorily. The fact that the width of that

portion of the oxygen mask which fits over the nose is fairly constant allows us to use the same measurement of frame in practically all cases.

The next photo shows the Bausch & Lomb sun glasses frame in place, resting on the oxygen mask, and demonstrates that the pilot is afforded a maximum field of corrected vision. It is to be noted that the optical centers of the lenses in this frame must be considerably nasal to the geometric center of the lenses but this is no major problem due to the fact that the only pilots who require correction to obtain normal vision have comparatively small amounts of correction and, for this reason, no gross prismatic effects are introduced when the pilot looks through other portions of the lens besides the optical center.

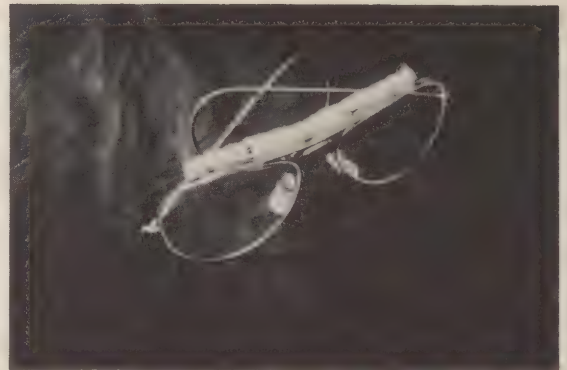
The next photo shows the sun visor being worn in the down position with no spectacles being worn by the pilot.

The next photo shows the Bausch & Lomb spectacle frame being worn with the visor of the P-1 helmet in place. Due to the great density of the visor it is impossible to get a clear view of the spectacle frame through the visor in this picture; however, the frame can be seen through the visor on one side. No difficulty is encountered in using the visor when this particular frame is being used.

The next photo is a side view with the sun visor in the up position and the Bausch & Lomb sun glasses frame being worn. This demonstrates quite well the large amount of lens which the pilot has to use in his lower field of gaze.

Another ophthalmologist raised the question of the restriction in the pilot's field of vision which might be introduced by the wearing of any type of spectacle. No matter how narrow the spectacle frame, it will naturally interfere when the pilot is attempting to look into the extremes of gaze. However, this objection is not considered to be valid in that the frame being used fits closely to the oxygen mask so that the nasal field of vision is very little affected by the narrow frame. The binocular field encompasses such a large area of the nasal field of each eye that no particular problem is evident by using the narrow spectacle frame.

A number of months ago one of our older and more experienced pilots, who requires a small correction, was fitted with a pair of Bausch & Lomb sun glasses frames and clear lenses and took them to Korea where he flew a large number of combat missions. Upon his return he reports the following: The glasses were worn without any discomfort, with no interference when the visor was in place. Before this pilot left for Korea he had used his spectacles on a number of occasions at our Base, which has a reputation for having a very low humidity. Due to the low humidity, even though it was quite warm, perspiration was no problem before take-off. On arriving in Korea during the summer he noted that, due to the relatively high humidity in that area, while taxiing and during the warm-up, he perspired profusely so that by the time he was a few thousand feet in the air the perspiration on his forehead had dripped down and streaked his spectacle lenses to the extent that he had to remove his glasses, clean them and replace them. As was stated in the first part of this paper, a jet pilot in combat does not have the time, space or facilities to remove his glasses, clean them and replace them while in flight. This objection to the use of spectacles while flying jet fighter aircraft is a serious one and must be overcome. We have a solution but, thus far, we have not had an adequate opportunity to prove that the solution is valid. We recognize that the ordinary sweat bar, which is made of plastic and is approximately one and one-half inches long, will not solve this problem because it extends over only a relatively small portion of the top of the spectacles. The Alameda Medical Depot have constructed a special sweat bar for us which extends over almost the entire top of the spectacle front. The absorptive material which we have selected is merely a strip of sponge rubber which is clipped in place to the metal sweat bar by surgical clamps.



This arrangement will allow for frequent changes of the sponge rubber when it becomes rancid and objectionable from the perspiration. It is hoped that this absorptive sponge rubber will take up enough of the perspiration from the forehead so that the lenses will not become streaked from the perspiration incident to his taxiing and engine warm-up period.

The following photo shows the Bausch & Lomb sun glasses frame with the extra long metal sweat bar to which the strip of sponge rubber is clipped.

The next photo shows the spectacle frame with the absorptive sweat bar being worn by the pilot. It is recognized that his narrow pad of sponge rubber may interfere very slightly with the pilot's vision in the upper field of gaze.

In summary, we recognize that some type of spectacle frame other than that which is currently being issued must be made available which will enable the pilot to wear it comfortably with his oxygen mask in place to get the maximum field of vision through the lenses and to prevent the lenses being streaked with perspiration. The frame which we have devised, although not perfect, is an attempt to meet these requirements.

We have noted one other difficulty at our Base which concerns the use of some type of protection for the pilot from glare. For a long time the pilots have been buying their own sun glasses, of all different shades and degrees of spectacle perfection. They have experienced considerable difficulty in obtaining issue sun glasses which were satisfactory to the individual pilot. The presently authorized plastic sun glasses are not acceptable for use by jet pilots because of their flimsy construction, their tendency to scratch very easily and, most of all, the fact that they are highly inflammable. For these reasons I have considered that they are dangerous and will not allow the jet pilots to wear them.

Since the inception of the N15 shade sun visor with the P-1 helmet considerable objection has come from the pilots as to its use. Many of them refuse to have the visor mounted on their helmet and continue to fly with their own personal sun glasses. When questioning a number of the more experienced and reliable pilots, several of whom have had many combat missions in Korea, I find that it is a matter of education of the pilots to demonstrate to them that the visor is an excellent piece of equipment. Almost all the pilots feel that a different type of catch should be used on the visor to enable them to pull it down into place more easily. They also feel that when it is mounted as prescribed, the visor, when pushed up, does not go up high enough so that when they are searching the sky for other planes above them the bottom portion of the visor interferes slightly with their vision.

We have considered the psychological aspect of the pilots' objections to using the visor and feel that a great many of the younger pilots particularly have a sense of claustrophobia when the visor is in place. They seem to feel that their vision is restricted even on a bright day by the use of the visor and will, more often than not, push it up out of the way. We have demonstrated on several occasions to pilots who have this attitude that their visual acuity is not reduced to any degree when the visor is in place. This was particularly demonstrated to one pilot who had just returned from Korea and who had used his visor a great deal and whose visor was quite scratched. Due to the close proximity of the visor to the pilot these scratches did not interfere with his visual acuity.

We have had some pilots who were keenly aware of the extreme brightness at high altitudes and have attempted to use a pair of sun glasses in combination with the visor. This practice has been forbidden because of the fact that the visor cuts out eighty-five per cent of the light and if the pilot wears sun glasses in addition to the visor so much of the light will be cut out that the visual acuity is bound to be reduced.

From conversations with the more experienced pilots it would appear that the presently authorized visor, which is attached to the P-1 helmet, is all that is necessary to cut down the excessive light at high altitudes and, for this reason, the issuance of sun glasses for flying jet aircraft is not warranted.

If those pilots who require a correction to obtain normal vision are supplied with clear lenses they will be able to use them with the visor in place during the day and with the visor in the up position at night. It is, however, believed that a sun glass of the N15 shade, made of glass and not plastic and mounted in a sturdy metal frame, should be allowed all pilots who ordinarily do not fly at altitudes of over ten thousand feet. There is unquestionably a considerable amount of fatigue which these pilots experience when not using a filter in bright sunlight.

Discussion:

- Dr. Rose wanted to know whether or not pilots objected to having their ears squeezed under and against the visor that Col. Bristow described.
- Col. Bristow said yes, they all do, but that his group has no answer for that problem yet.
- Dr. Hulburt expressed sympathy for the pilot wearing the visor, pointing out that sometimes the sun is not overhead and the pilot would not want to wear dark glasses.
- Col. Bristow explained that the visor can be in the "up" position any time the wearer wants it that way. At 35,000 or 40,000 feet, Col. Bristow said, the visor is necessary, and the more experienced fliers find it to their advantage to use it at that altitude. At lower altitudes, the visor can be placed in the "up" position, then pulled down whenever the pilot wishes.
- Dr. Blackwell said it was his understanding that all the data on the brightness of the sky indicated that the sky gets dimmer as one goes up.
- Col. Bristow said this is true for very, very high altitudes, but that the fighting takes place at 35,000 to 40,000 feet. It was his personal feeling that it is brighter at 35,000 to 40,000 feet than at 10,000 feet.
- Dr. Hulburt offered the idea that the glare does not come from the sky, but from the sun on the surrounding plane parts, etc.
- Dr. Kuhn wanted to know the lowest uncorrected acuity allowable in the Air Force.
- Col. Bristow said that 20/20 is required. However, there are pilots who have flown for many years and who may need glasses, but since they are experienced and extremely valuable, they are still permitted to fly.

HIGH ALTITUDE VISIBILITY

Lt. Col. George O. Emerson, USAF (MC)
Aero Medical Laboratory
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

In this presentation, I shall first name the known visual difficulties at high altitude, and give our reasons for considering one of these to be the most important to be investigated at the present time. Then I shall relate some of the evidence for considering this such a problem, and then give our analyses of the course of this difficulty, and what we think can be done about it. Mr. Glover will describe the method by which we are starting to obtain illumination and brightness data.

The visual problems associated with high altitude are: First, air to air visibility; second, air to ground visibility; third, workspace illumination and fourth, glare. Nearly all of us are well acquainted with certain peculiarities of high altitude visibility. These are the single source character of that from the upper hemisphere, and the diffuse, frequently highly intense character of that from the lower hemisphere. Apart from the single source of illumination, the upper hemisphere has an homogenous background. At times, this is also true to a more limited extent, of the lower hemisphere. In other words, it is more homogenous than when seen from lower altitudes.

Considering the four problems, we are most interested in air to air visibility for several reasons. The detection of targets has greater operational importance than either glare or variations in workspace illumination. Also, developing protection against glare and providing adequate illumination in the cockpit, are not too difficult. Now I shall compare the remaining two problems, detectability of ground and air targets. High altitude missions are concerned with strategic ground targets. These are usually amenable to radar detection. Besides, meteorology is a more important element than the peculiarity of high altitude illumination, in the detection of ground targets, and so illumination studies would not yield conclusive information on their detectability. Stated conversely, there are several reasons for our predominant interest in air targets. They are not as susceptible to radar detection. Second, illumination studies are expected to yield some conclusive information on the detectability of air targets. Third, air targets merit some priority consideration because they have to be dealt with acceptably before there is an opportunity of detecting ground targets.

The difficulties in interception above 35,000 feet are common knowledge. When two aircraft attempt to rendezvous at forty or forty-five thousand feet, over a certain town, frequently they both spend fifteen or twenty minutes over the town conversing by radio, but fail to find each other. If the other aircraft is sighted, the pilot may look away a moment; when he looks again toward the plane he cannot find it. If the plane is picked up by radar, its position being known, it may come in very close before it is seen. I have interviewed a number of Korea veterans relative to this problem, some of whom have had experience above 50,000 feet. One of them described how he was in a flight of F-86's that chased a flight of Migs for a hundred miles, knowing their clock position and that they were always within 1 to 5 miles horizontally from them during the entire chase. They never saw these Migs until they themselves had turned at the Yalu, and then looking back they saw the Migs letting down at an estimated eight miles.

It might be interesting to relate some of the Communist tactics. The Migs run a race track pattern. From their airfields across the Yalu, they climb toward the north and then

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fly south. At times a flight stays in the contrail level for the entire course. Of course they are easily detected. The catch to it is this, there is another flight above the contrail level, which our planes cannot see. If our planes come up to attack the Migs forming contrails, the undetectable upper flight sees the additional contrails formed by our planes, and comes down to attack them.

The contrail level here and in Korea usually extends not lower than 30,000 and not higher than about 44,000 feet. The reciprocating engines of the B-36 have been observed leaving a thin smoke trail when above the contrail level.

The Migs, up until February of this year, had a very shiny aluminum surface. Our pilots wondered if they had a bunch of washers on each plane, who spent all their time shining them up. It made our pilots ashamed of our Sabre jets. In February, they started painting them a dark color, which made them very difficult to see when they were above and when below without undercast. It didn't seem to affect their visibility against an undercast. This is consistent with what we have observed and predicted about contrast ratios. In April, they were using a powder blue undersurface, and then a number of different surfaces were seen.

Above 40,000 feet, most sightings are by glints, which is pilot parlance for specular reflections. In the absence of contrails, the most experienced pilots I have interviewed estimate that about 90% of the fighter sightings are by glints. The estimate is lower for bomber sightings.

There has been one verbal report of photography difficulties above 45,000 feet.

Some pilots have reported a peculiar sensation about the eyes when searching at higher altitudes. Could this be a disturbance of accommodation and/or convergence, caused by the homogenous background? The statement is frequently made that there is nothing on which to focus. Another statement that pilots repeatedly make is that the plane seems to blend with the background. In one mission of practice interception, arranged by the Aero Medical Laboratory, that blending did exist, especially when the plane was more than 30° above the horizon. Most of the pilots experienced at high altitudes say the most difficult place to detect another aircraft is when it is below, without undercast, the above position running a close second. Another plane is comparatively easy to detect against an undercast. This conforms to my own observations.

You may have observed that at lower altitudes, the plane is darker than its background at least 90% of the time. The exception is when the plane is 180° from the sun. Most present day aircraft have skins of aluminized alloys which have a reflectance between 70 and 80%. The proportion of that that is specular is very high. So with a predominantly single source of illumination only a small diffuse reflection will be received in most positions.

The best that we can figure is that poor visibility at higher altitudes is mostly the result of low contrast ratios. Above we see a dark plane against a dark background, with little opportunity for glints. When below, if there is no undercast, there is also a dark plane against a dark background, except when approximately 180° from the sun.

We would like to obtain as exact as possible illumination and brightness figures in order to decrease the contrast ratios on our own craft and to establish principles that will assist us in the detection of enemy aircraft.

Suppose, after going to much trouble to get such information, it should become general knowledge, available to the enemy. The greatest potentiality that it offers is in avoidance of direct visual detection rather than in teaching how to detect other aircraft. Since we

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evidently possess some greater electronic capability, in comparison with our probable enemy, he would have to rely more on visual detection. Therefore, the general possession of such knowledge would appear to be to our advantage.

Discussion:

Dr. Duntley congratulated Lt. Col. Emerson and his staff on their start on the difficult problem of atmospheric optics measurements at high altitude. Dr. Duntley said his own group would rush data urgently needed by lots of different people in their work in this area. He felt, however, that the real need was for flights through different weather conditions. He was impressed with the fact that Lt. Col. Emerson seemed to be able to operate more simply and at higher altitudes than any other way he knew of. Dr. Duntley hoped the temperature correction problem had been thoroughly looked into. He voiced approval of the work being done in the direction of smaller solid angles of light collection and also suggested that it might be interesting to work in the direction of bigger solid angles--180 degrees. Brightness data--arrived at by automatic integration--he considered a good idea, and concluded by saying he hoped Lt. Col. Emerson's program would produce a great deal of data.

Lt. Col. Emerson said that temperature and fatigue factors had been taken into account.

Dr. Hulburt also offered compliments on Lt. Col. Emerson's program. He added that quite complete data are available for the upper atmosphere and that his group could help by supplying such data.

Dr. Penndorf was asked for information on the rocket data collected by the Air Force Cambridge Research Center, but since he had not participated in this work he could not offer many details. He said, however, that several flights had been made to determine brightness and that he thought there were three rocket flights which were successful.

Dr. Penndorf emphasized the difficulty of measuring brightness from rockets due to the fact that one is not certain where the rocket is pointing. Dr. Penndorf stated that it seemed that the sky brightness above 30 km. is greater than it should be according to theory. He emphasized, however, that the rocket flies in a horizontal path at high altitudes than at low altitudes. Such an effect could conceivably contaminate the brightness data.

HIGH ALTITUDE VISIBILITY

Harold C. Glover
Aero Medical Laboratory
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

In the planning phase of the high altitude visibility study, consideration was given to the two commonly used equipment carriers, balloons and rockets. The selection of balloons was made for the following reasons. The balloons will carry the necessary equipment to the altitudes at which aircraft can be expected to operate in the immediate future. The rate of ascent of balloons is much more favorable for precise measurements than the very rapid rate of ascent of rockets. Another advantage which balloons have over rockets is that launchings may be made from numerous areas and not confined to the uninhabited largely desert areas of the country, thus the data should be of more practical use from an Air Force operational standpoint. And finally, the relative cost decidedly favors the choice of balloons.

Polyethylene balloons with an inflated diameter of 72.8 feet, are employed on these flights. Performancewise they will carry the equipment to an altitude of 90,000 feet in approximately 2 hours. The rate of ascent being about 800 feet/min. Just below the balloon in the loading chain is a release timer; this consists of a simple clock mechanism which can be set to parachute the equipment at any selected time. A demand release mechanism has been developed by the Aero Medical Laboratory to permit actuating the release by a radio signal from the ground. This controlled release is a considerable improvement over the clock release procedure particularly for flights of fairly long duration where the difficulty of recovery is considerable. Next in the loading chain is a cargo chute which hangs in an open position, thus obviating any opening requirement. Descent by parachute from 90,000 feet requires approximately one hour. To complete the loading chain is a radar tracking banner and the instrument box.

The following is a description of the light measuring equipment as used on the first trial flight and some modifications which are under consideration. The light sensitive elements are barrier type photoelectric cells as manufactured by the Weston Electrical Instrument Corporation; the model nomenclature is 856RR-V. These are hermetically sealed cells equipped with the Viscor filter so that the spectral response closely approaches that of the eye. Microammeters of three different ranges are used with the photoelectric cells, i. e., for those cells directed toward the dark upper portion of the sky, a range of 0-20 is used, while for the downward directed cells, a range of 0-500 is indicated, and for the intermediately bright areas, meters are used having a range of 0-200.

The field of the photocells is limited to 20 degrees by a cylindrical tube painted dull black inside to reduce reflections. The field has the characteristics imposed by two circular stops, i. e., if a point source is moved across the field, the cell response curve is similar in shape to the normal distribution curve. The choice of the field size depended upon the sensitivity of the equipment and was considered a minimum for the zenith cell in order to provide adequate response. In the interest of uniformity, all of the cells have the same 20 degree field. Provided the field is of uniform brightness, the field size is unimportant; however, because of brightness variations near the sun and near the horizon, measurements in these areas will not be accurate. This limitation is realized and a lens system is being considered to reduce the field without grossly affecting the cell response. Improved methods to reduce the reflections within the field limiting tubes are also being considered; among these is the application of flocking to the inner walls.

Due to the large balloon above the instrument box, zenith measurements are not possible from this position. In order to make a zenith measurement, a gimbal mount is attached to the top of the balloon, permitting the attached light-sensitive cell to assume a zenith direction at all times during flight. The other photoelectric cells are attached directly to the instrument box.

For the first flight, one cell was placed in the zenith gimbal and two cells were positioned 45 degrees above the horizon and connected in parallel to one meter. All of the other cells were used singly with separate meters in the following positions: 15 degrees above the horizon, 15 degrees below the horizon, 45 degrees below the horizon and at the nadir position.

The recording equipment consists of a 35 mm Bell & Howell spring-wound camera which intermittently photographs the instrument panel. A full winding provides approximately 400 single frames, which permits recording for approximately a three-hour period when 30-second intervals are selected. A timing mechanism which consists of a battery-operated intervalometer pulses the panel lighting system and the camera. Relays are used to permit the light intensity to peak before the camera solenoid is actuated. The power pack consists of four Williard NT 6 batteries which provide a 24-volt supply. These batteries are contained within a pressurized cell to prevent boilaway at high altitude.

Along with the microammeters which are mounted to an instrument panel is an altimeter, a magnetic compass, a clock and a thermometer. Information is thus simultaneously recorded from each of these instruments. The light-sensitive cells are all directed in one vertical plane; thus the azimuth position can be determined from the compass reading for each brightness measurement. The position of elevation of the light-sensitive cells is fixed for each flight; variations in elevation, however, can be made over a series of flights. Instrument box rotation is expected to provide complete azimuth coverage.

The photoelectric cells and microammeters are calibrated as units, i.e., once the particular individual cell and meter combination has been selected, this combination remains the same during calibration and use. Also the calibration is accomplished with the field restricting tube and the electrical wiring connections which are actually used during the flight. This is considered particularly important for the zenith cell and meter combination; approximately a total of 400 feet of wire is necessary to complete this circuit. The basic calibration is accomplished with the Macbeth illuminometer. A secondary source is used consisting of a large white matt surfaced card placed in the shade but under a blue sky. Care is used to make certain that both the cell-meter reading and that recorded with the Macbeth are made from the same position relative to the card. The linearity of response is evaluated by replacing the white card with a series of Munsell gray scale cards of graded reflectance values.

Plans include additional measurements to determine the solar illumination at the altitudes of interest. This may be accomplished by directing one photoelectric cell to 45 degrees above the horizon and employing a vertical slot as a field restricting device. Gondola rotation should position this slot so that occasionally the cell is maximally illuminated at the time of recording. This reading can be corrected for the cosine effect by computing this value from the sun's elevation which may be determined from the time record.

The application of phototubes and multiplier circuits is being considered in order to reduce the field size and thus provide more accurate data in the areas of brightness variation. Such a receptor with a vertical scanning prism could cover all areas of interest except those obstructed by the balloon. This, however, is of considerable size, amounting to as much as 50 degrees, when the instrument box is suspended the usual 40 to 50 feet below the balloon. It is intended that improvements be made to the equipment and methods as this project progresses.

REPORT OF THE WORKING GROUP ON VISIBILITY AT HIGH ALTITUDES

by

Seibert Q. Duntley

Visibility Laboratory

Scripps Institution of Oceanography

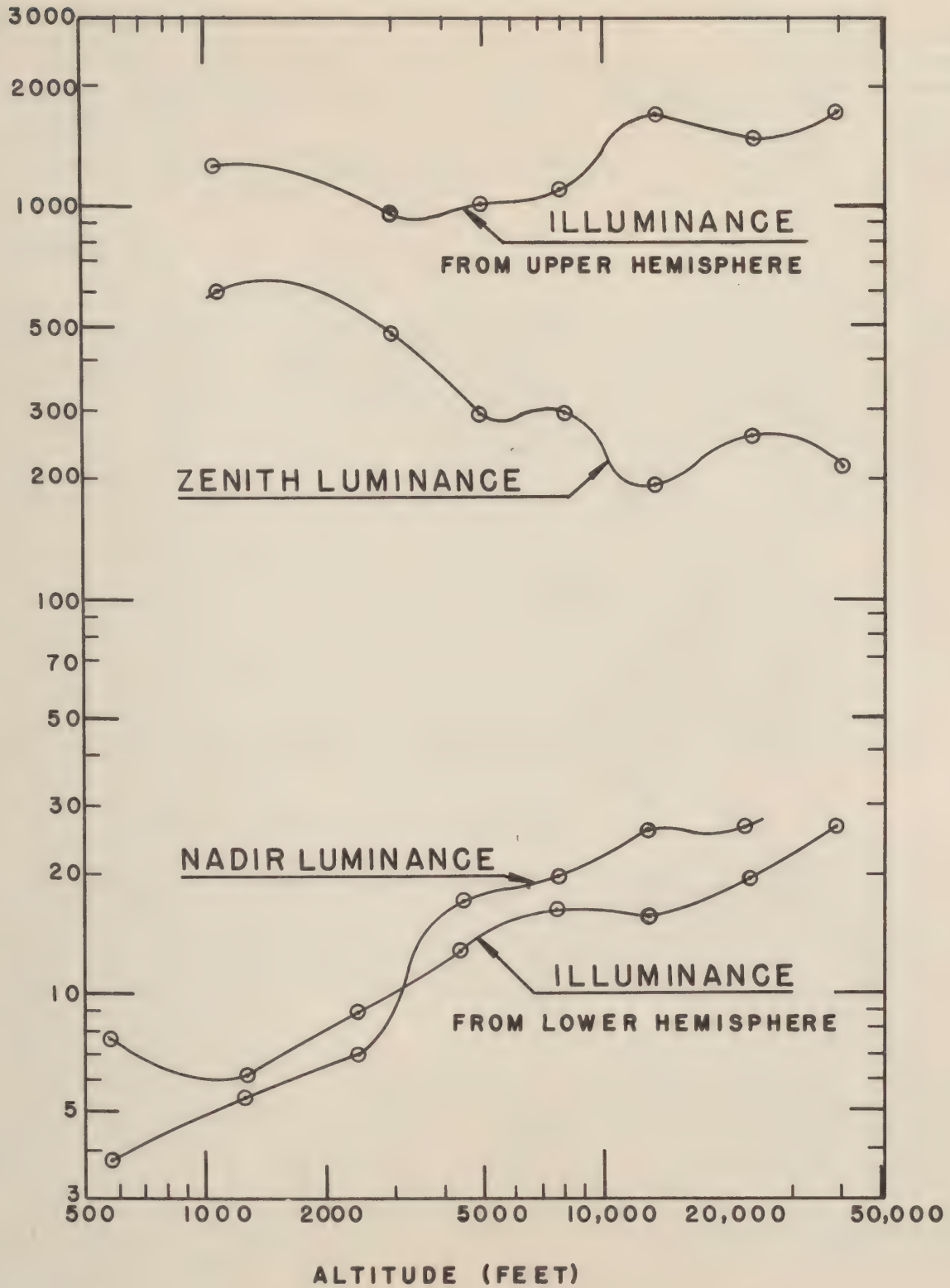
This working group, established initially to consider the visibility problems of the Strategic Air Command of the U.S. Air Force, made recommendations to the Vision Committee (see Minutes of the 29th Meeting, p. 23) which resulted in the establishment of the Visibility Laboratory of the Scripps Institution of Oceanography in San Diego, California. This laboratory, staffed at present by personnel transferred from the Visibility Laboratory at MIT, is jointly and equally supported by the Air Force and the Navy under contract NObsr-43356 between the Navy's Bureau of Ships and the University of California. Funds are being supplied by the School of Aviation Medicine, USAF, by the Bureau of Ships, and by the Office of Naval Research. The laboratory occupies a group of three buildings totalling approximately 6,000 square feet of floor space on the grounds of the Navy Electronics Laboratory on Point Loma in San Diego, California. The present staff of 15 is expected to be enlarged to 25 as rapidly as qualified personnel can be obtained. In addition to excellent shop and laboratory facilities, derived in part by the transfer from MIT of equipment furnished by the Bureau of Ships and by the Office of Naval Research, the Visibility Laboratory has unparalleled facilities for field experiments. These include the five research vessels of the Scripps Institution of Oceanography, a research submarine, and a research aircraft promised by the Research and Development Command, USAF. The cooperation of Pacific Fleet units in San Diego is also an important potential asset to the laboratory. Close liaison is maintained with the Navy Electronics Laboratory, particularly the Human Factors Division under Dr. Arnold M. Small. Potentially valuable contacts have been established with the Naval Ordnance Test Station (Inyokern, California), the Rand Corporation (Santa Monica, California), and other government and research activities in California.

In accordance with the recommendations of the Vision Committee, referenced above, it is expected that the new laboratory will provide headquarters for military visibility problems and information, a facility for research in those topics in optics and psychophysics which require advancement in the interest of military visibility calculations, and a center for research on certain military instrumentation problems.

In addition to the establishment of the Visibility Laboratory, the Working Group on Visibility at High Altitudes has undertaken several activities designed to provide needed basic data. Dr. E. O. Hulburt has collated all available data on the distribution of light within the atmosphere, interpolated and extrapolated these data by means of theory, and has prepared a paper entitled "Measurements and Estimates of Sky Brightness for all Altitudes of the Sun for various Altitudes of the Observer above the Surface of the Earth." This work has been used as a basis for providing the Strategic Air Command with some of its more urgently needed answers. The Visibility Laboratory has under construction several spherical enclosures, designed upon data from Dr. Hulburt's paper, which will serve as "artificial skies" within which model aircraft can be photometered to determine their inherent contrasts under flight conditions.

A week before this meeting members of the staffs of the Visibility Laboratory, the Vision Research Laboratory of the University of Michigan, and Operations Analysis SAC cooperated in a high altitude flight using two B-36 aircraft. The two airplanes flew in formation

LUMINANCE (FOOTLAMBERTS), ILLUMINANCE (LUMENS/SQ. FOOT)



five hundred feet directly above and below each other. Each ship made photometric photographs of the other plane at eight logarithmically spaced altitudes up to 40,000 feet. The photometric data shown in the accompanying figure were obtained at the same eight altitudes by means of MacBeth photometers. The data were taken over the ocean off Astoria, Oregon, during a three-hour period centered on noon of 8 November 1952. The sky was free of local clouds, but the atmosphere was composed of several haze strata. This departure from standard atmospheric structure is evident in the photometric data. Inherent contrasts of the aircraft have not yet been reduced from the photometric photographs.

SOME FACTORS AFFECTING THE RELATION BETWEEN REPORTED VISIBILITY AND VISIBILITY FROM AIRCRAFT*

C. A. Douglas
National Bureau of Standards

1. Introduction

The use of the visibility reports of weather observers at airports to determine whether approaches to an airport may be made under visual flight rules, under instrument flight rules only, or whether the field is closed to traffic implies a relation between these reported visibilities and the visual guidance received by the pilot. This relation might be expected to be one of equality, one of proportionality, or possibly only a one-to-one correspondence between the reported visibility and the guidance received by the pilot. It is found in practice that none of the above assumptions are valid. The deviations are frequently attributed to errors in the observations of the weather observer, to differences between the thresholds of the stationary observer and the moving pilot, and to variations in the fog or haze density with height above the ground, i. e., differences between "slant" and horizontal visibility. These are important factors and are being investigated.^{1, 2}

The purpose of this report is to illustrate the effects of some of the other factors which affect the relation between reported and pilot visibilities and to demonstrate their relative importance. These factors are: 1) The degree to which the reported visibility is representative of the conditions at the time and place of landing, 2) the restrictions imposed upon the field of view by the structure of the aircraft, 3) the time required by the pilot to find the identifying marks or lights after they come above threshold, 4) the effects of terrestrial background, 5) the intensity distribution of the approach and runway lights, and 6) the path of the aircraft with respect to the marks or lights.

2. Effects of Variations in Fog or Haze Density

The variations in fog or haze density with time and from point to point are a frequent source of differences between the reported visibility and the guidance received by the pilot. It is not possible to determine the transmittance of all possible paths between every point in the flight path of the aircraft and the ground and there will always be some difference between the time of the approach and the time of the visibility observation. Hence, a certain stability and uniformity of conditions must be assumed when the visibility observations are applied to the landing.

Under conditions of poor visibility the atmosphere is seldom stable or uniform but generally varies from moment to moment and from point to point. The extent and rapidity of these variations are illustrated in Figures 1 and 2. These figures show records of measurements of the atmospheric transmission over a 500-foot path made by NBS transmissometers.³ Time runs from right to left on the charts. The interval between two parallel arcs is 15 minutes. Increasing transmission produces an upward movement of the pen line with the top of the chart corresponding to a transmission of 1.0. Conversion scales at the left of the charts may be used to obtain the visibilities corresponding to different transmissions. The periodic returns of the pen lines to the zero position are the result of automatic hourly checks.

*This investigation was sponsored by the Visual Landing Aids Section, Bureau of Aeronautics, Navy Department.

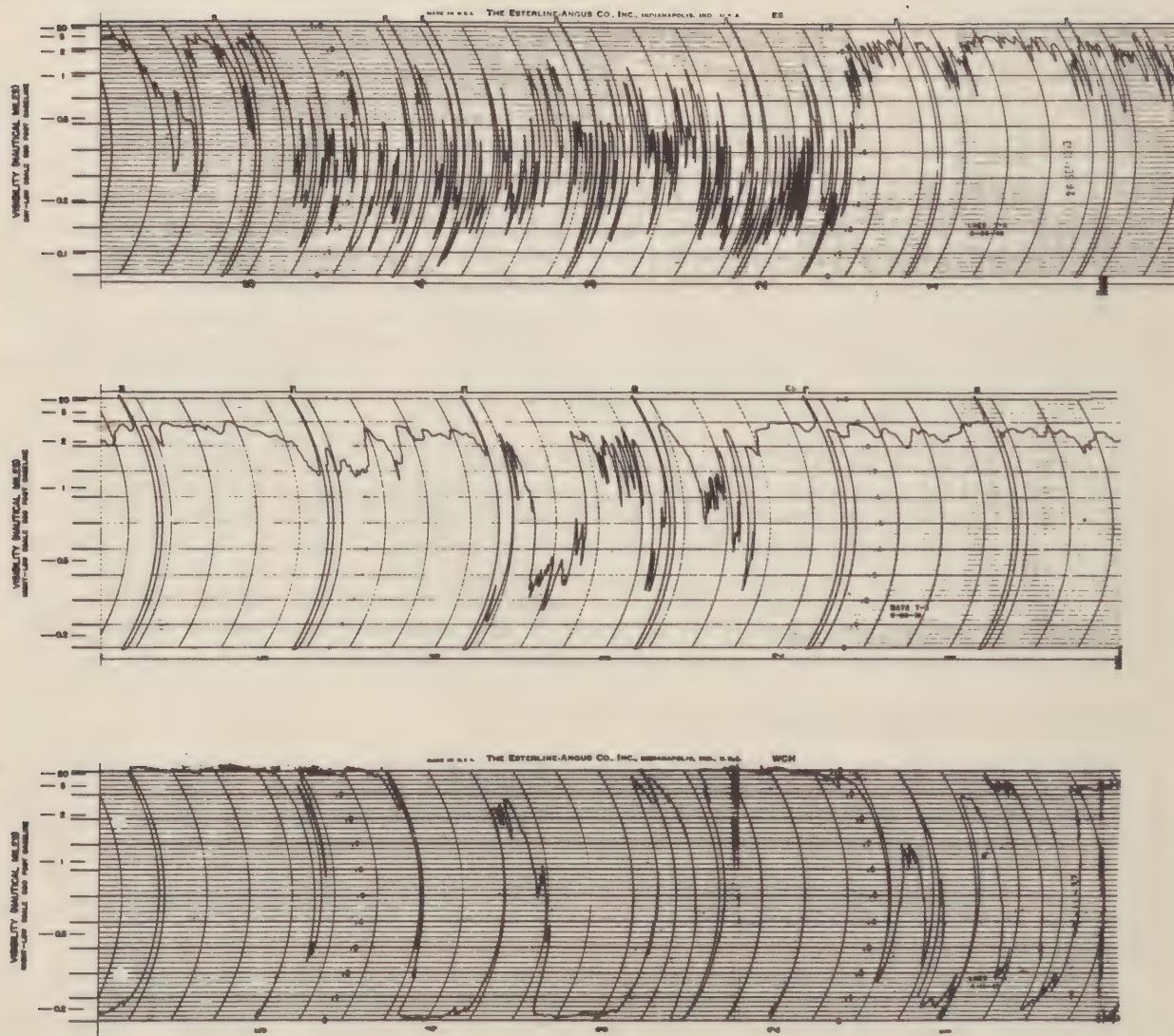


Figure 1. Records of Atmospheric Transmission Measurements Over a 500-Foot Path.

VISIBILITY (NAUTICAL MILES)
DAY-LOW SCALE 500 FOOT BASELINE

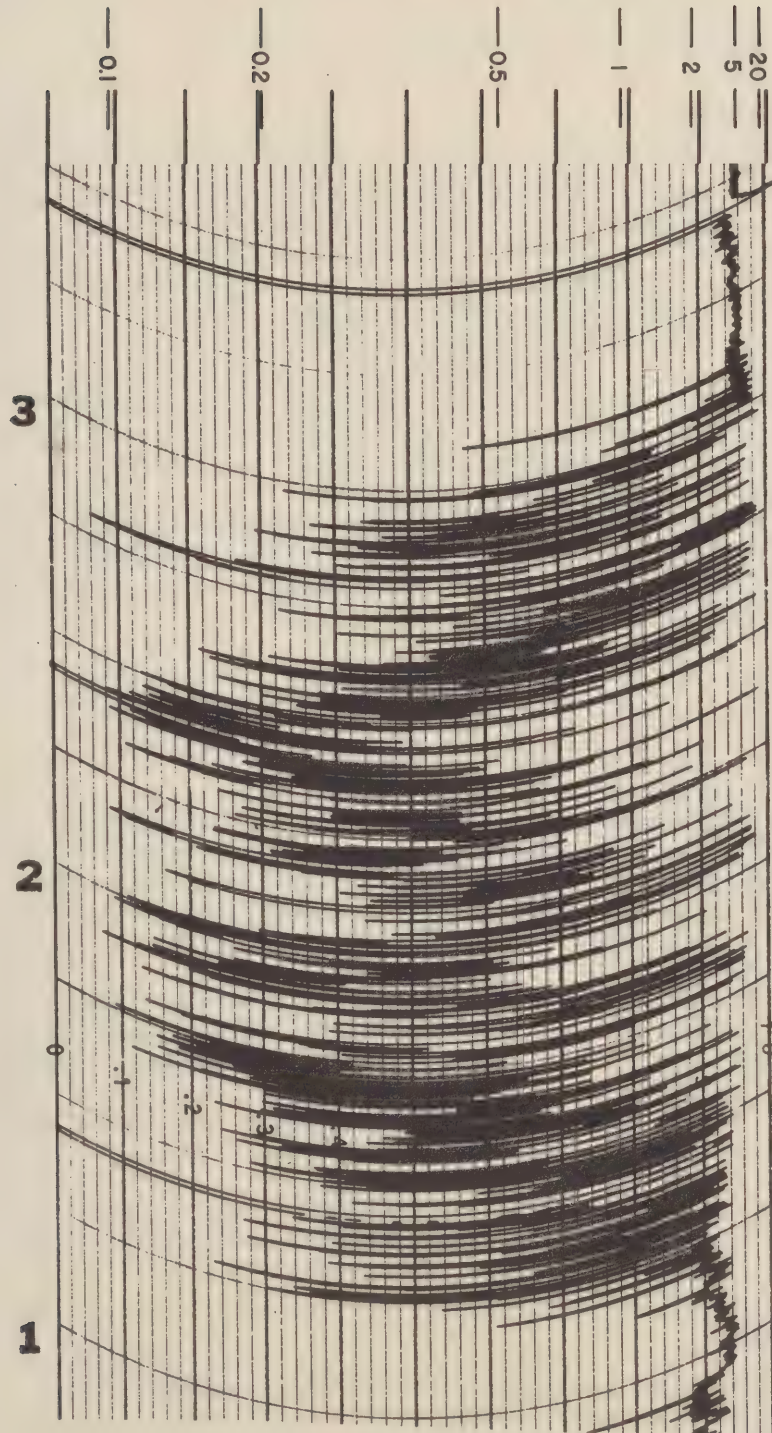


Figure 2. Variations in Transmission Over a 500-Foot Path.

These charts illustrate the suddenness with which conditions can change and the short periods for which conditions are stable. These sudden changes with time are generally associated with similar changes with location. Since the situation can change so rapidly with time and with location, it is imperative that the visibility reports applicable to landing aircraft be made as close to the landing in time and in place as is possible. Even then the variability of the weather will set an upper limit to the accuracy and applicability of visibility reports in determining the guidance the pilot will receive.

3. Effects of Cockpit Cutoff

One of the impressions a pilot frequently gets during a low visibility landing is that the visibility improves as the aircraft comes nearer the ground. This effect is often real. At other times it may be the result of restrictions in the pilot's field of view caused by the structure of the aircraft. This effect is illustrated in Figure 3. The length of the broken line V_p represents the distance the pilot can see. Thus the intersection of this line with the ground plane is the most distant point which can be seen. If θ is the maximum angle of view downwards, no marks nearer the aircraft than the intersection of the line making this angle with the horizontal and the ground plane can be seen. The heavy line segment d , therefore, represents the guidance distance, the region in which objects can be seen. If the aircraft comes nearer the ground, as indicated in the lower part of the figure, the intersection of the line V_p and the ground plane moves slightly farther from the aircraft while the intersection of the line indicating cockpit cutoff and the ground plane moves considerably closer to the aircraft, causing a large increase in the guidance distance. This increase in guidance distance is frequently interpreted as a change in the fog density, especially when the guidance distance is short. When the guidance distance is large, the pilot pays little attention to either extremity of the guidance range.

By simple trigonometry it can be shown that if V_p is greater than $h \operatorname{cosec} \theta$, the guidance distance is given by

$$d = (V_p^2 - h^2)^{1/2} - h \cot \theta \quad (1)$$

where h is the height of the aircraft above the ground plane. In Figure 4 are shown curves giving the guidance distance as a function of the height of the aircraft for several values of pilot visibility for cockpit cutoff angles of 10 and 15 degrees. These angles are representative of the minimum and maximum angles of view downward through the forward cockpit windows of transport-type aircraft.⁴

It is generally considered that an experienced pilot requires a guidance distance of at least 500 feet in order to perceive a sufficient portion of the approach and runway pattern to fly by visual reference alone. Note how close to the ground the aircraft must be in order to obtain this guidance distance when the visibility is low. Note also the large effects of small changes in height or of changes of the lateral position of the aircraft which will change the cutoff angle at which the pattern may be viewed.

These variations in guidance distance with height and with the position of the aircraft add uncertainties to the forecasting of the distance from the runway at which the pilot will be able to fly by visual reference alone.

4. Effects of Search Time

When visibility observations are made by the ground observer, he has, in effect, a nearly unlimited time to find the mark he is seeking. He is familiar with the location and uses various cues to locate the position of the mark. The situation of the pilot is different. He is approaching the runway or the approach lights at a speed of approximately 200 feet per second. During the time he is seeking the mark he may have to control the aircraft and so

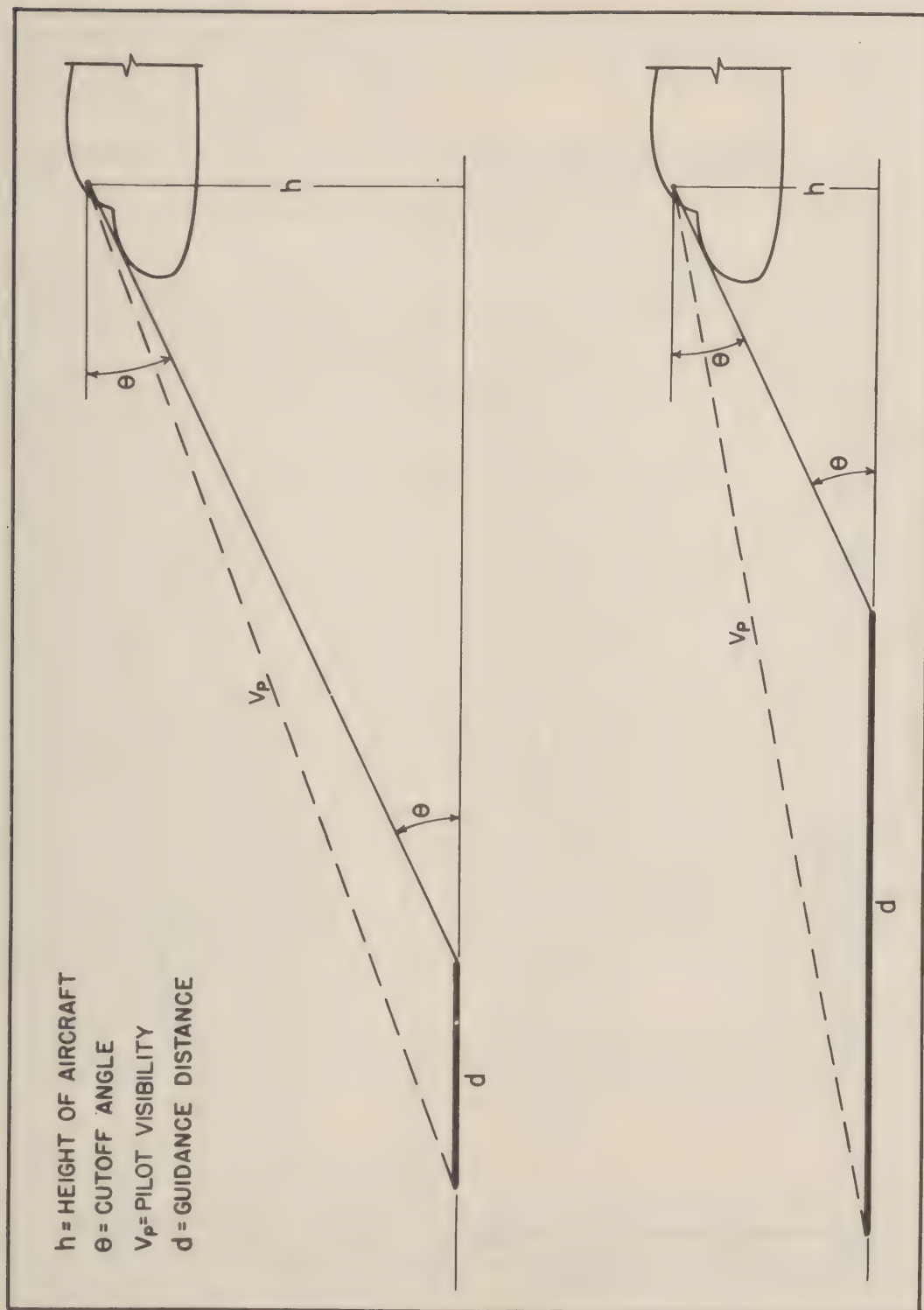


Figure 3. Effects of the Structure of the Aircraft on Guidance Distance.

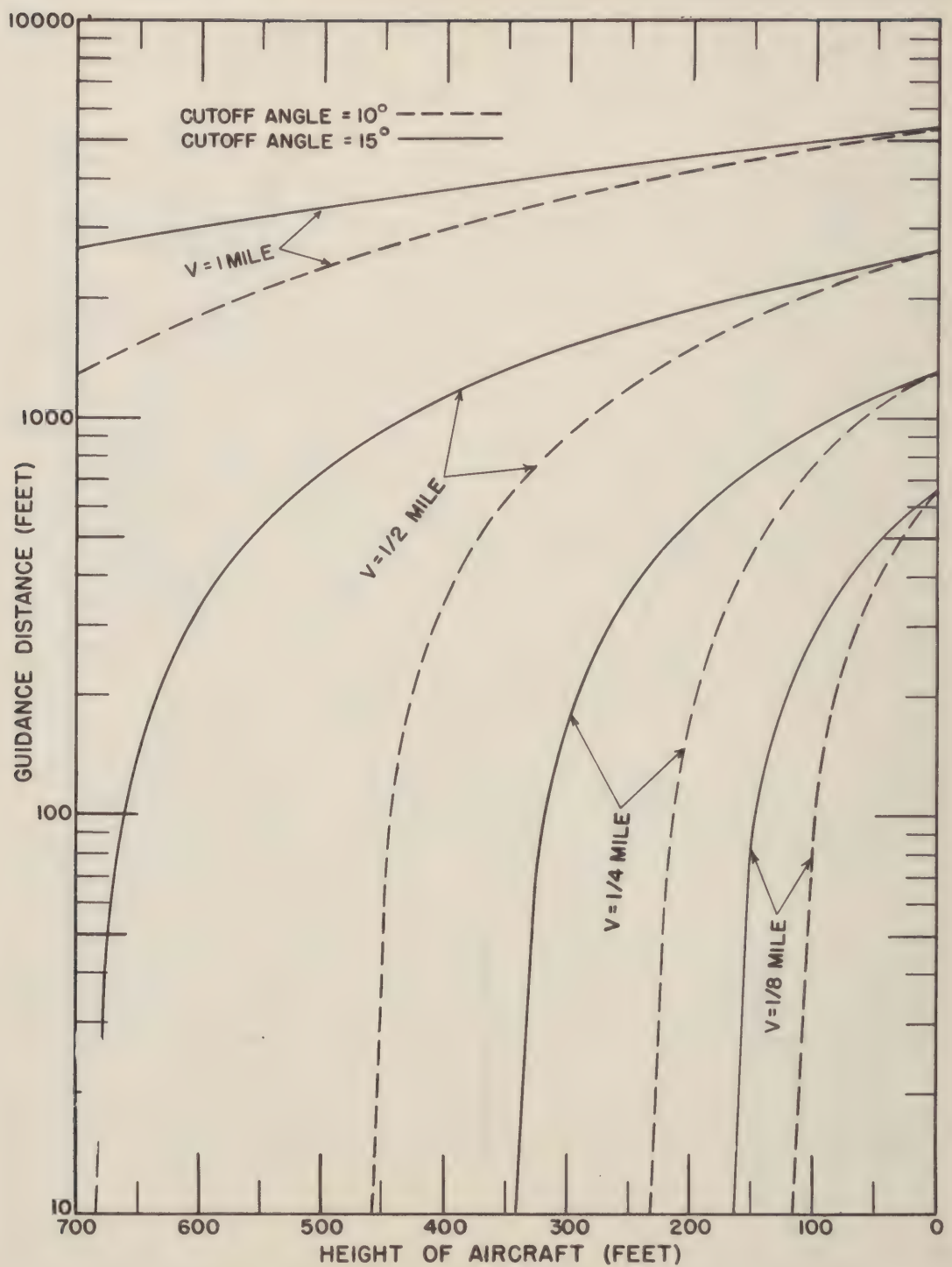


Figure 4. Relation Between Guidance Distance and the Height of Aircraft.

is unable to give his full attention to the search. Cues may be completely absent. It is extremely difficult to find marks or lights which are at or near threshold when their exact position is not known.⁵ A mark or light will be in a position to be seen only for the time required for the aircraft to travel a distance equal to the guidance distance. Hence, a single mark may not be found by the moving pilot although he would see it if he were stationary. At best it may be found only after the distance to the mark is much less than the visual range of a stationary observer.

The effect of the time required to find a mark on the visibility factor is shown in Figure 5. The visibility factor K is defined as the ratio of the apparent visibility to visibility which would be obtained by a stationary observer and was computed from the relation

$$K = V_p/V_s = (V_s - St/3600)/V_s \quad (2)$$

where V_p is the distance in miles at which the pilot will find the mark, V_s is the distance in miles at which it could be found if the pilot were stationary, t is the time in seconds required to locate the mark and S is the speed of the aircraft in miles per hour. This equation holds for all values of t less than $3600 V_s/S$. When t is greater than this, V_p and K are zero. An approach speed of 120 miles per hour was assumed in computing the curves of Figure 5.

The problem of determining the time required by the pilot to locate the marks or lights is a complex one. Generally there is not one but a pattern of marks or lights to be found and recognized. These patterns vary in inherent contrast or intensity among themselves and in apparent contrast or intensity as the position of the aircraft changes. In the early stages of the approach, the difference in the distance to the aircraft from the two ends of the guidance region is small (Figure 3). Hence there are no large differences in apparent contrast of the marks in the guidance region resulting from the effects of atmospheric attenuation, and all marks may be near threshold. As the altitude of the aircraft decreases, there are more marks or lights in the field of view, and since the distance from the near end of the region of guidance to the aircraft decreases markedly, the apparent contrast of marks in this part of the guidance region will be considerably greater than that of marks in the outermost part. Consequently, the time required to find the pattern is less when the aircraft is low. When more data relating threshold to time of search are available, it will be possible to grind out the probability for the detection of marks or lights as a function of the path of the aircraft and the atmospheric conditions. At present only an estimate can be given. On the basis of flight test experience at the Landing Aids Experiment Station it is estimated that, on the average, from two to five seconds are required to locate the runway or approach pattern after the pattern comes above threshold. At times the pattern will be seen sooner and at times none of an approach light pattern will be seen because the pilot never looked at the right place at the right time.

The effect of the search time has a significant effect on the visibility factor only when the visibility is poor. Then the possible variation in time of search adds another uncertainty to the problem of predicting the point at which the pilot will obtain sufficient guidance to fly by visual reference.

5. Effects of Terrestrial Background

Probably the most important factor in producing differences between reported and pilot visibilities is the difference in viewing conditions. The observer is instructed to use large, black (or dark) marks viewed against a sky background. The pilot generally views marks with an immediate terrestrial background. The distance at which a black mark can be seen against the sky can be obtained from the familiar relation:

$$\epsilon = e^{-\sigma V_0}$$

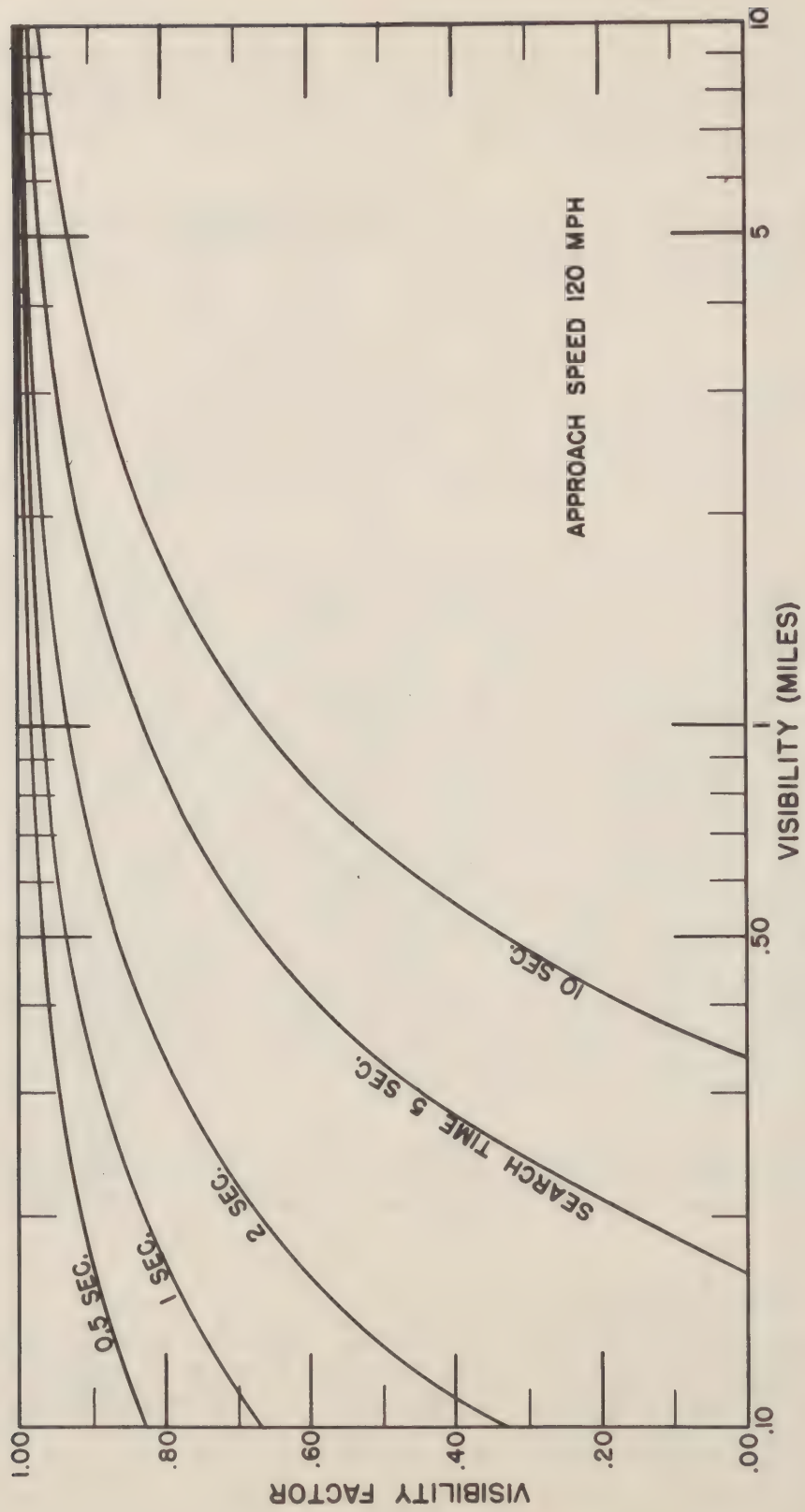


Figure 5. Effects of Search Time.

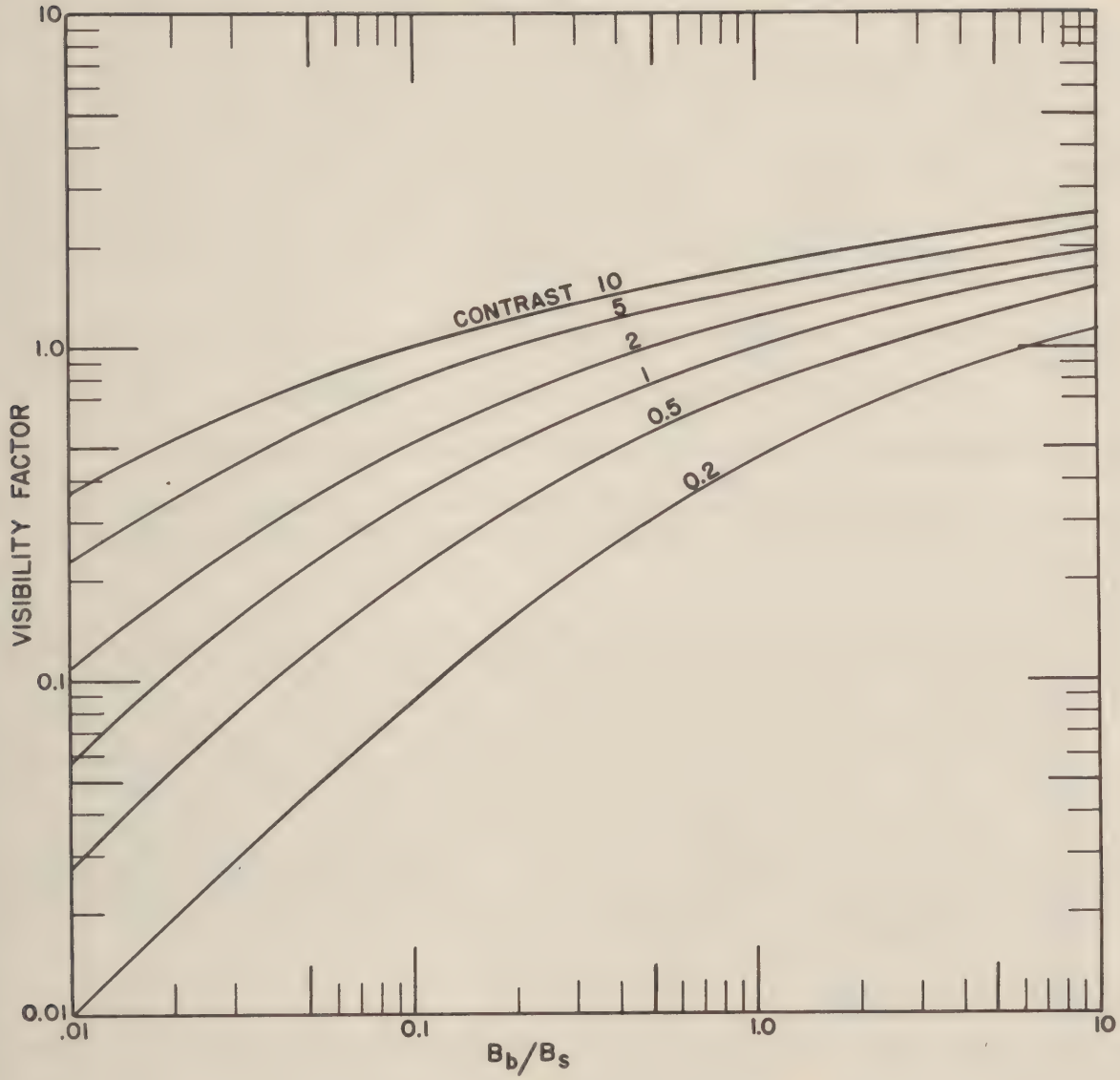


Figure 6. Effects of Terrestrial Background.

where ϵ is the contrast threshold of the observer, σ is the attenuation coefficient, and V_o is the reported visibility. This visibility is independent of the luminance of the background sky and of the direction of view with respect to the sun. The distance at which a mark viewed against an immediate terrestrial background can be seen can be found from the relation developed by Duntley.⁶

$$\epsilon = C_o \left[1 + (B_b/B_s) (e^{\sigma V} - 1) \right]^{-1} \quad (4)$$

where C_o is the inherent contrast between the mark and its background, V is the distance the mark can be seen, B_b is the inherent luminance of the background and B_s is the luminance of the horizon sky in the direction making the same angle with the line of sight as does the sun. Here the apparent contrast and therefore the distance a mark can be seen is a function of the direction of view, the luminance of a particular section of the sky and the inherent luminance of the background as well as of the contrast of the mark and the background. When the line of sight is horizontal, B_s is the luminance of the portion of the sky directly behind the mark and its background. In the case of a landing aircraft it is within a few degrees of the horizontal projection of the line of sight.

The visibility factor K can then be obtained by combining equations (3) and (4) so that

$$K = V/V_o = \log \left[1 - (B_b/B_s) (1 - C_o/\epsilon) \right] (\log 1/\epsilon)^{-1} \quad (5)$$

Note that K is independent of the visibility or transmittance of the atmosphere.

The results of computations of the visibility factor by means of this equation are shown in Figure 6. A value of 0.05 was used for the contrast threshold ϵ in making the computations.

In considering the curves the following values may be helpful. The ratio B_b/B_s varies from about 5 or more with sunlit snow as the background and a clear sky to less than 0.01 in directions near a low sun shining through haze on a grass background. It is in the region 0.2 to 0.3 in the case of a grass background on an overcast day. This ratio may vary by a factor of more than 10 around the horizon on hazy days when the sun can be seen through the haze. The contrast of a runway and its marks or its background is generally in the range 0.5 to 2.0. Contrasts between natural objects and their backgrounds may be as low as 0.2.⁷ The conditions at the upper right-hand part of the figure are not common and generally require, in order to produce both a high contrast and simultaneously a high value for the ratio B_b/B_s , that sunlight be specularly reflected from the mark. In general, therefore, the visibility factor will be less than one, ranging from 0.3 to 0.6 under overcast daylight conditions to less than 0.1 with a low sun shining through haze.

6. Visibility Factor for Lights

In addition to the use of natural marks, the pilot frequently uses runway and approach lights for guidance.

The relation

$$E_o = I e^{-\sigma x} / x^2 \quad (6)$$

may be used to find the maximum distance x at which a light of intensity I can be seen by an observer with an illuminance threshold of E_o when the angular size of the light is sufficiently small so that it can be considered a point source and when the luminance of the "flashed" portion of the light is much greater than the difference between the luminance of the background and that of the unlighted light fixture. In general, both the above conditions hold sufficiently well for airport approach and runway lights at the distances which are of

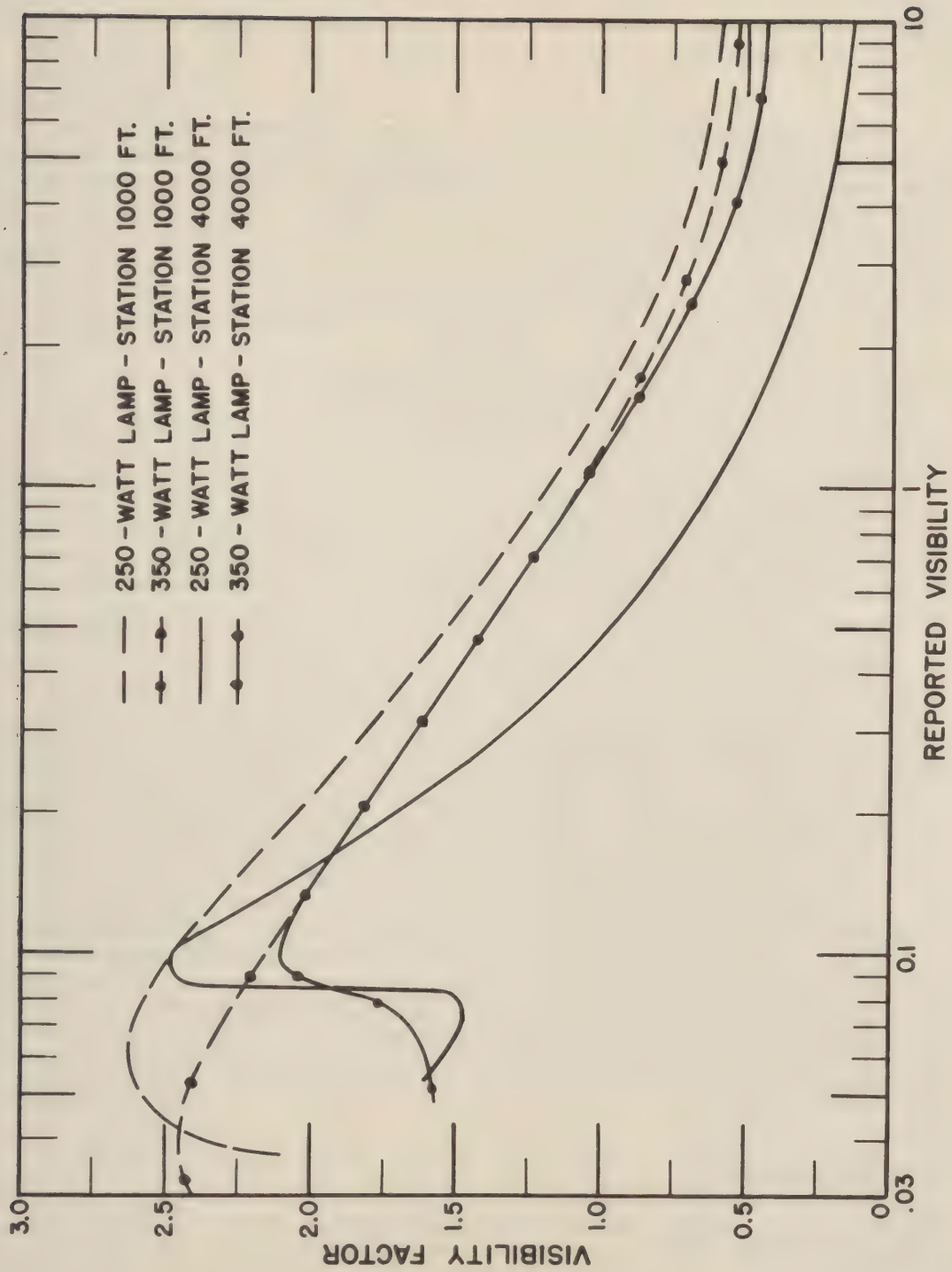


Figure 7. Effects of Candlepower Distribution Upon the Visual Range Factor of Two Types of Approach Lamps.

concern so that no significant errors are introduced by the use of equation (6). The observer's threshold is a function of the apparent luminance of the background of the lights. Hecht⁸ has shown that the relation between the threshold illuminance and background luminance may be expressed as

$$E_B = E_O (1 + kB^{\frac{1}{2}})^2 \quad (7)$$

where E_O and k are constants and E_B is the threshold illuminance applicable to the background luminance B . At night B is low and E_B becomes nearly constant and equal to E_O . For bright daylight conditions E_B becomes approximately proportional to the background luminance. For values of B between 2 and 400 candles per square foot, Tousey and Hulburt⁵ have found that

$$E_B = kB^{0.84} \quad (8)$$

The visibility factor may be obtained by means of equations (3) and (6) so that

$$\epsilon^K = E_B \times 2/I = E_B K^2 V_O^2 / I \quad (9)$$

$$K = x/V_O$$

where x is the distance between the aircraft and the light and I is the intensity of the light in the direction of the aircraft. Lights used in aviation service are usually directional luminaires with large changes in intensity resulting from small changes in the angular position of the observer. The intensities of lights used range from a few candles in the stray-light region to more than 100,000 in the peak of some runway and approach lights. In addition, the intensity of runway and approach lights is adjustable in five steps from a relative intensity of 0.0016 to full intensity. Since the intensity of the light is a function of the orientation of the light unit, its intensity distribution and the position of the aircraft with respect to the light, and the distance to the light as well as atmospheric transmittance and the intensity setting of the lighting system, a general expression for K is not possible. The degree to which these factors affect the visibility factor for two types of sealed-reflector approach-light lamps with somewhat different vertical beam spreads is shown in Figure 7. In obtaining the curves of this figure it was assumed that the threshold illuminance is 1000 mile candles (typical of bright overcast conditions), that the contrast threshold is 0.05, that the lamps were operated at 100% intensity, and that the path of the aircraft is on the line formed by the intersection of the 3° instrument landing system glide path and a vertical plane through the line of the lights. The intensity of the lights in the direction of the aircraft was obtained from candlepower distribution measurements of typical lamps. The station numbers refer to the distance from the location of the lights to the intersection of the glide plane with the runway and correspond to locations near the inner and outer ends of an approach-light system. Note the variation in K between types of lamps and between lamps at the two stations. Changes in the height of the aircraft above the ground can cause variations in K similar to the variations between the lamp types or between the stations at which the lights are located. Variations in lateral position have less effect because of the wide horizontal beam spread of the lamps.

7. Numerical Examples

The following numerical examples will emphasize the degree to which the factors discussed above affect the guidance received by the pilot.

Case 1. Assume the reported visibility is 3 miles, the contrast of the runway and its marks is 1.0 and the ground-sky ratio is 0.3 (overcast conditions). The visibility factor for this ground-sky ratio is 0.63. Hence the pilot visibility is 1.9 miles. The effects of search time and of cockpit cutoff are of little significance here. If a search time of 5 seconds is required, the search time factor is 0.93 and the pilot will be 1.8 miles from the runway when it is located.

Case 2. The approach path of an aircraft lies over an area giving no guidance, e.g. smooth water or snow, so that the end of the runway is the first mark which can be seen. The contrast of the runway and the background is 0.5 (black-top on grass). The ground-sky luminance ratio is 0.075 and the reported visibility is 3 miles. The visibility factor is then 0.17. Hence the pilot visibility is 0.5 miles. Assuming a cockpit cutoff angle of 10° , the pilot cannot see the runway unless he is within about 450 feet of the ground plane and cannot obtain a guidance distance of 500 feet unless he is within 370 feet of the ground plane. Assuming that a search time of 5 seconds is required to locate the end of the runway, the search time factor is 0.67. The pilot will then be only 0.33 miles (0.67×0.5) from the end of the runway when he locates it. If he is following a 3° ILS glide path to touchdown, he will be only 150 feet above the ground plane at this time so that by the time he finds the runway, cockpit cutoff will not be a restricting factor.

Case 3. Assume the reported visibility is 3 miles, that an approach-light system using the 350-watt lamps is being used, and that the pilot's threshold is 1000 mile candles (bright overcast conditions). The visibility factor is 0.70 and the pilot visibility for the lights is 2.1 miles. As in case 1, the effects of cockpit cutoff and of search time are of little significance.

Case 4. Assume visibility is 0.3 mile, a 350-watt lamp approach-light system is being used, and the pilot's threshold is 1000 mile candles. The visibility factor is 1.65 for lamps at any station. Hence the pilot visibility for the lights is 0.5 miles as in case 2.

8. Recommendations

It has been shown that many of the differences between the reported visibility and the guidance the pilot receives can be explained on the basis of the factors discussed in this paper without recourse to such factors as the effects of motion and attention or difference in adaptation level on the threshold of the pilot, errors in the observations or variations in the threshold of the weather observer, or of the variation of fog density or transmittance with height above the ground although these factors are also significant. It is also apparent that the effects of variations in fog density with time and place, the effects of variations of the guidance distance with the position of the aircraft, and the effects of variations in the time of search, limit the accuracy with which the guidance the pilot will obtain can be forecast. There are, however, several steps which will improve a quite unsatisfactory situation. Among these are the following:

1. Choice of landing direction. The simple expedient of not landing in the up-sun direction under critical conditions can increase the visibility factor significantly.
2. Greater use of the present lighting aids in hazy weather particularly when the sun is low.
3. Installation of high intensity range lights to mark the extended centerline of the runway.
4. Provision for runway markings of high contrast and of sufficient angular size so that they are effective at distances as great as three miles. By proper choice of the directional reflectance of the marks and their background it should be possible to obtain a visibility factor of nearly one for most daylight illumination conditions.
5. Making visibility observations more representative in time and place. This course is now being actively pursued.⁹

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6. Application of the visibility factors discussed in this paper and of other significant visibility factors to the reported visibilities to obtain a measure of the visual guidance the pilot can expect. Use the guidance so determined in place of reported visibilities in describing weather conditions to the pilot and in determining whether an airport is open, instrument, or closed. An operational study should be made of the accuracy of those measurements of guidance which can be used usefully. Then it can be determined which of the parameters affecting the visibility factors it is necessary to measure accurately with complex instrumentation, which can be determined with sufficient accuracy by simple instrumentation, and which require only tables of representative values. The science of instrumentation has been developed to the point where the chief limitations in instrumentation are the economic factors of installing and maintaining the equipment.

In closing it is strongly recommended that much greater emphasis be placed upon developing means of improving the guidance given the pilot (this will at the same time reduce the variations in the visibility factor) than in the development of instruments which can do no more than tell how bad the visibility is.

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Discussion:

- Mr. Stickle complimented Mr. Douglas for bringing together in a very fine paper a wide field of knowledge and applying it to a specific problem.
- Maj. Best reported that the Air Force Weather Service had a good record of weather observing in connection with the Berlin Airlift and there was a minimum of embarrassing incidents such as Mr. Douglas mentioned, although there were aircraft coming in every few minutes. However, no one there paid any attention to the visibility prediction made by the meteorologist; he simply watched the plane ahead of him. Maj. Best noted that there is an increasingly vocal school of thought which feels that the solution to this problem is a work-horse aircraft constantly flying around in the airfield traffic pattern.
- Dr. Allen referred to Dr. Sloan's paper and raised the question of whether or not stereopsis is a serious factor in aircraft pilotage. He thought that perhaps a series of stripes parallel to the flight path down the runway would serve as a stereo target, whereas tire marks, etc., details of grass, could not be used as stereopsis cues.

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FOVEAL DETECTION THRESHOLDS FOR VARIOUS DURATIONS OF TARGET PRESENTATION*

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Visibility predictions depend upon two basic kinds of data: (a) information concerning the transmission of light by the atmosphere; and (b) threshold data of the human eye. Visibility predictions reported to this Committee by the speaker and by Dr. Duntley in recent years have depended upon the threshold data reported to the Committee by the speaker at the 15th meeting, in February 1946. The present report presents new threshold data which are intended to supplement the earlier data for use in making visibility predictions.

The 1946 data included three sets of threshold data. The first set of data involved targets brighter than their background. The target appeared in one of eight possible locations on a 15-degree orbit about a central orientation marker. The target appeared for 6 seconds, and the observers were required to search for it among the eight possible positions along the known orbit. With such a procedure, the observers gave themselves a target presentation for some fraction of 6 seconds. The precise "exposure" duration of the target was unknown. It depended upon the mode of search and the speed of eye movements. The threshold data were obtained under these experimental conditions because, in 1943-1945, Navy lookout procedure involved a scan-rate approximately equal to the 15 degrees traverse in 6 seconds required by the laboratory procedure. The procedure did not simulate actual situations exactly, of course, since in practice the observers would not know in advance that the target could only occur in eight positions along a path scanned.

A second set of experimental data was obtained under identical conditions, except that the targets were darker than their background.

A third set of data was obtained under conditions designed to maximize the probability of target detection. The target always appeared in one position. The target was presented for long durations, such as 10-30 seconds. The actual duration varied among experimental conditions. Each experimental session involved use of two target durations, one twice as long as the other. The experimental data were retained only if it could be demonstrated that there was no difference in probability of detection between the shorter and the longer durations. Thus, these experimental conditions represent the thresholds of detection when time is unlimited. These data are of obvious usefulness when one wishes to compute the limiting visibility range.

All three sets of experimental data were obtained under the condition that the observers employed the mode of viewing which gave them optimal detection. The observers themselves set the mode of viewing to achieve optimal detection, based upon their experiences in practice sessions. It was not feasible to record exactly how the observers viewed the target under different experimental conditions. The observers reported using direct (foveal) viewing at high background luminance and indirect (peripheral) viewing at low background luminance. Other than this, however, nothing is known about the position the target occupied on the retina.

This procedure has the practical justification that observers in the field also learn how best to direct their gaze in making target detections. It has the undesirable feature that the data are comparatively useless for predictive purposes if the observer in the field does not

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know approximately where to expect the target to appear. In such cases, we need to evaluate target visibility in terms of the location of the target on the observer's retinae, and the location will usually differ markedly from the location providing optimal target detection. The importance of this limitation on the threshold data increases with the increase in speed of military targets such as aircraft. Aircraft may be expected to pass through the observer's visual field so rapidly that the observer will often have insufficient time to orient his gaze for optimal detection. It is virtually impossible to predict target visibility under these conditions from the 1946 data.

What is obviously required is a sensitivity map of the entire visual field. This map must be made at all background luminance values of military interest. Target variables such as duration, size, internal contrast, and speed of movement must be studied at each luminance level. The present study represents a small beginning toward providing the requisite data. We have obtained threshold data for the foveal visual field with size, duration, and background luminance as the experimental variables.

Procedure

The basic experimental task of the observers was to detect the presence of a disc target which was produced by adding a luminance increment to a small portion of a screen of uniform luminance. The screen constituted an inner wall of a cube whose dimensions were approximately 7 feet on a side. Walls of the cube were coated with white sphere paint. The observers were situated 10.25 feet from the screen. The screen of uniform luminance thus subtended approximately 40° at the eyes of the observers. Other walls of the cube were also visible which were nearly as bright as the screen. These walls extended the visual field of approximate uniformity to at least 60° in every direction. The observers used normal binocular vision with natural pupils. Two observers were employed throughout, who observed together.

Light sources for the illumination of the screen were incandescent lamps placed at the rear of the cube near the observers, but completely shielded from their view. The number and wattage of the lamps was varied to adjust the quantity of illumination falling upon the screen. In order to insure uniformity of luminance of the screen, direct illumination from the lamps was shielded. The apparent color temperature of the screen was 2850° K.

The target was produced by transillumination of a milk-plastic screen which served as the major portion of the screen wall. Size of the target was determined by the physical size of the aperture through which the beam transilluminated the plastic screen. The aperture was pressed tightly against the rear surface of the plastic. The plastic was paper-thin. Consequently, the definition of the edge of the target was excellent. Four target sizes were employed subtending approximately 1, 4, 16 and 64 minutes of arc at the observers' eyes.

The target luminance was produced by a high-output projection system based upon a special ribbon-filament lamp, which was operated at 2850° K.

The target always appeared in a known location in the center of the screen. The subjects utilized four bright points, which were arranged in a diamond pattern, for fixation and orientation purposes. The four points were arranged symmetrically about the target. The separations of the fixation and orientation points were determined on the basis of preliminary experiments so that the target was maximally discriminable at all times. The separations among the fixation points varied from 36 minutes in the case of the smallest target to 80 minutes in the case of the largest target. In each case, the observers fixated the center of the configuration of fixation points. Thus, all the data refer to central foveal vision. The intensity of the fixation points was adjusted to approximately ten times their contrast threshold. Supplementary experiments indicated that fixation lights of this intensity will have minimum influence upon the discriminability of nearby targets.

The observers were not allowed to judge directly whether or not they detected the presence of the target. They were required to prove their ability to detect its presence by correctly identifying the time interval of four possible intervals in which the target occurred. The temporal intervals were each 2.5 seconds long. Following the four intervals, the observers were given 8 seconds in which to select the temporal interval they considered the target had occupied and to record their choice by depressing one of four response buttons. The observers then had 2 seconds in which to prepare themselves for the next presentation of the target.

It is shown elsewhere** that requiring subjects to prove that they can discriminate is preferable to accepting their own direct evaluation of their ability to discriminate. The data obtained under the former conditions are both more reliable and more valid.

Each experimental session consisted of 250 target presentations, 50 at each of five target luminance increments intended to elicit from nearly zero to nearly 100% correct detection. Each experimental session was divided into five sub-sessions, each of which contained 10 presentations of each of the five target luminance increment values. Each sub-session lasted about 17 minutes. At the end of each sub-session, the observers were allowed a 5-10 minute rest and relaxation period. The entire experimental session lasted nearly 2 hours.

The presentation of the targets and the recording of responses was facilitated by automatic equipment. The schedule for presentation of targets was governed by coded holes in a paper tape. Appropriate metal roller contacts were excited through the holes and activated electrically controlled projection apparatus through mediation of a relay panel. The timing of all stimulus presentations depended upon a synchronous motor and a system of cam contacts situated on the drive shaft of the motor. The magnitude of the target luminance increment was varied by a filter-selector device which could interpose one or another Wratten neutral filter in the projection beam. The interval occupied by the target could be varied by operating a shutter at one of four possible times. "Verification" equipment was provided, so that the accuracy of the electrical components in providing the desired stimulus conditions could be established.

The stimulus conditions for each presentation and the temporal interval selected by each observer were recorded automatically. The recorder was composed of 28 solenoid-driven precision punches which made coded holes in a lightweight cardboard record sheet.

The correctness of the selection made by each observer on each presentation was established by series relays and recorded by means of a bank of electric counters. One counter recorded the number of correct selections made by each observer for each target luminance increment.

In the rare event that the electrical components failed to provide the stimulus conditions required by the tape, all record of the presentation was automatically eliminated.

The basic data from each experimental session were proportions of correct answers for each observer at each of the five target luminance increments. There is, of course, a probability of .25 that the observer will get the correct answer by chance alone. The effect of chance successes may be eliminated by the formula:

$$p' = \frac{p - .25}{.75} \quad (1)$$

**H. R. Blackwell. Psychophysical Thresholds: Experimental Studies of Methods of Measurement. Eng. Res. Bull. No. 36, University of Michigan Press, 1953.

where p = raw proportion
 p' = corrected proportion

Throughout the remainder of this paper, we will refer exclusively to values of p' as defined by equation (1).

The duration of the target presentation was given seven different values in different experiments: 1, 1/3, 1/10, 1/30, 1/100, 1/300, and 1/1000 seconds. Control of the target duration depended upon a large metal disc which rotated in the projection beam. The target was presented whenever an aperture in the disc was aligned with the projection beam. The time required for the target to increase to full luminance was only 1/10,000 second, which was always a small fraction of the target duration.

The two observers whose data are reported here were graduate students at the University of Michigan, specializing in sensory psychology. One was male, the other female. The observers were unusually interested in the experiments. Their visual acuity was known to exceed 20/20. Two other observers were used for a portion of the same experiments. These observers were undergraduates whose interest in the experiments was reasonably great but not exceptional as was the interest of the graduate students. The data from all four observers appear to be very similar. Only the data for the two graduate student observers are presented here since only these observers observed under all the experimental conditions.

Photometry of the screen luminances was performed directly with a Macbeth Illuminometer, fitted with a lens attachment to image the screen in the Macbeth cube. Photometry of the two largest targets was accomplished in a similar manner. Photometry of the two smallest targets was accomplished by what might be called a "candlepower box." A closed metal box was made with an opal disc at one end and a small aperture at the other. The aperture was fitted snugly against the screen so that the transilluminated target lay entirely within it. The target thus became a source for illumination of the opal disc at the other end of the box. Baffles were placed within the box to eliminate interreflections. The luminance of the opal disc was measured routinely with the Macbeth. From the transmission of the opal disc and the inverse square law, the intensity of the transilluminated target could be determined. From known size of the transilluminated target, the luminance of the target could be computed. Two "candlepower boxes" were used, one for each of the two smallest targets.

The target luminance increment was adjusted to the appropriate value for each experimental condition by means of Wratten gelatine filters placed in the projection beam. The transmissions of these filters were determined on an optical bench photometer. The calibration of all photometric instruments depended upon lamp and test-plate standardizations made by the Electrical Testing Laboratories of New York.

Results

In all, 162 experimental sessions were conducted in which background luminance, target size, and target duration were varied.

We may well begin by considering the basic form of the data obtained by each observer in a single experimental session. The basic data are proportions of correct detections, after correction for chance successes, and the contrast between target and background, defined as follows:

$$\text{Contrast} = \frac{\Delta B}{B} \quad (2)$$

where ΔB = luminance increment of the target
 B = luminance of the screen in the absence of the target.

In Figure 1 we have exhibited a theoretical curve which has been found to adequately represent the experimental data of all the present experiments. We note that the probability of forced-choice detections increases in a sigmoid fashion as the contrast of the target increases. The theoretical curve is a normal ogive, the integral of a normal frequency distribution. Our data analysis procedure involves determining the particular ogive which best fits the five experimental points obtained by each observer in each experiment. The ogive varies in two parameters, designated M and σ . The value of M is usually called the threshold; it is the target contrast at which $p' = .50$. The value of σ measures the steepness of the ogive. Sigma is actually the standard deviation of the normal distribution from which the ogive is obtained by integration. When σ is large, the ogive is flat.

The most appropriate ogive is determined for each set of experimental data by a procedure called the probit analysis. This procedure gives us values of M and σ for the ogive which best fits each set of data, and also provides us with a measure of the goodness of fit of the experimental data to the theoretical curve. Curve fits for all the present data were entirely acceptable.

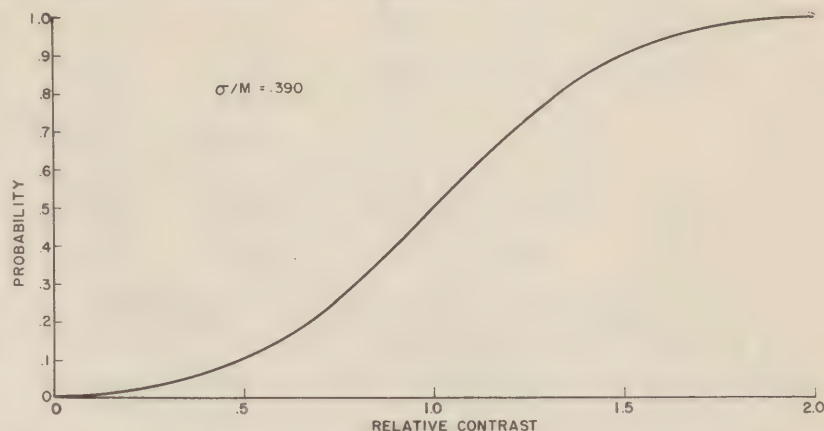


Figure 1. The relation between probability of forced-choice detection and target contrast found in all the experimental data. The curve is an integral of a normal frequency distribution, with parameter values: $M = 1$ and $\sigma = .390$.

Values of M varied over a million to one as background luminance, target size, and target duration were varied. Preliminary examination of the experimental data revealed the existence of a simple relation between M and σ , as M varied over this tremendous range. Values of M and σ were directly proportional, that is $\sigma/M = \text{constant}$. There is considerable evidence for this relation in earlier experiments. As we shall see, the existence of this simple relation between M and σ simplifies the problem of reporting and using the present experimental data.

The average values of σ/M for all the experimental data were .384 for one observer and .396 for the other. The theoretical curve in Figure 1 represents $\sigma/M = .390$, the average value for the two observers.

We have computed average values of σ/M for both observers in terms of each of the three experimental variables. These are presented in Table 1. Considering that values of M vary over a million to one, values of σ/M are remarkably constant. The differences as a function of target size appear haphazard. The values of σ/M appear to decrease as B increases, although the effect is small. The values of σ/M appear to decrease as duration decreases, although the effect is still comparatively small. Before indicating the use to which these values will be put, let us consider the functional relations between values of M and the three basic experimental variables.

Values of M are plotted as a function of B for each of four sizes and for each of seven target durations in Figures 2-8. In each case, values of M refer to the ordinate marked 50% probability of forced-choice detections. These are threshold contrasts, where as usual the threshold is defined by 50% detection. All plotted points represent averages of the data from the two observers. In most cases, the points are based upon one experimental session but in several cases, two experimental sessions were conducted under essentially the same conditions. The experimental data presented in Figures 2-8 represent a total of 81,000 observations by the two observers. The experiments required daily experimental sessions for more than 12 months.

Table 1: Average Values of σ/M

Target Size (Minutes of arc)							
	<u>1</u>	<u>4</u>	<u>16</u>	<u>64</u>			
	.373	.417	.396	.385			
B (foot-Lamberts)							
<u>.001</u>	<u>.1</u>	<u>.3</u>	<u>1</u>	<u>3</u>	<u>10</u>	<u>30</u>	<u>100</u>
.419	.421	.389	.386	.387	.380	.374	.355
Duration (seconds)							
<u>1</u>	<u>1/3</u>	<u>1/10</u>	<u>1/30</u>	<u>1/100</u>	<u>1/300</u>	<u>1/1000</u>	
.485	.450	.374	.370	.361	.361	.332	

The experimental points plotted at $\log B = -3.0$ require explanation. The background luminance in these experiments was actually considerably smaller than .001 foot-Lamberts. In fact, no background luminance was provided, except for negligible amounts of stray light. The experimental data for B equal to approximately zero cannot be plotted in terms of contrast for comparison with the other data unless we assume B to be finite. We take the evidence reported elsewhere in these Minutes by Blackwell and Law to demonstrate that threshold ΔB is proportional to B for small values of B. Hence, if we know the value of threshold ΔB , we can associate it with any convenient small value of B. We have assumed

$B = .001$ foot-Lamberts for convenience in plotting the present data. (All values of threshold ΔB for small values of B fall on a line of slope -1 on the graphs of our experimental data. This line has been drawn through the points at $\log B = -3.0$ to make our assumption explicit.)

Let us now consider the most convenient manner in which to evaluate different levels of probability of forced-choice detection. We have plotted values of M, corresponding to a detection probability of 50%. We wish to know the correction to make in M to allow for a different detection probability than 50%. Let us define Z, a conversion factor which will correct M to correspond to other probability levels, where

$$Z = 1 + f_a \cdot \sigma/M \quad (3)$$

where f_a = a factor to allow for the probability level derived from standard tables of the normal frequency function.

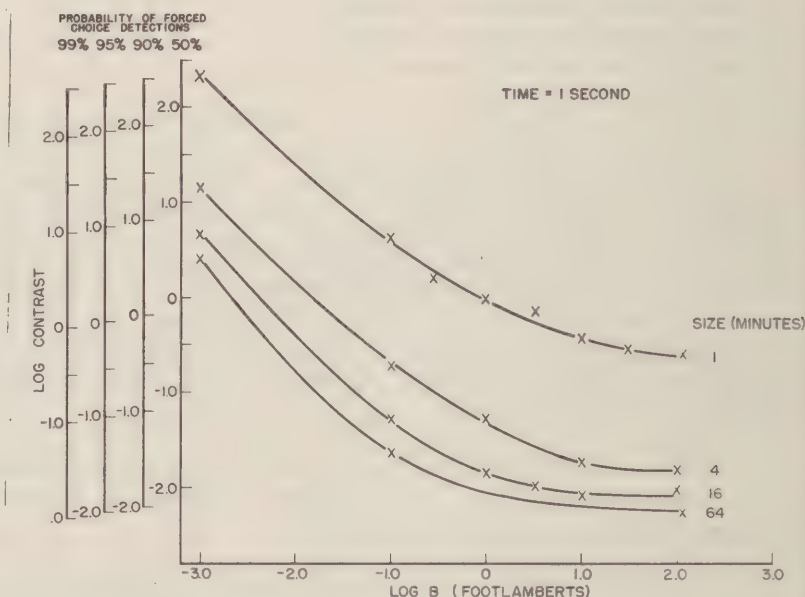


Figure 2. Data obtained with a time of exposure of 1 second. Each point represents at least 500 responses by two observers.

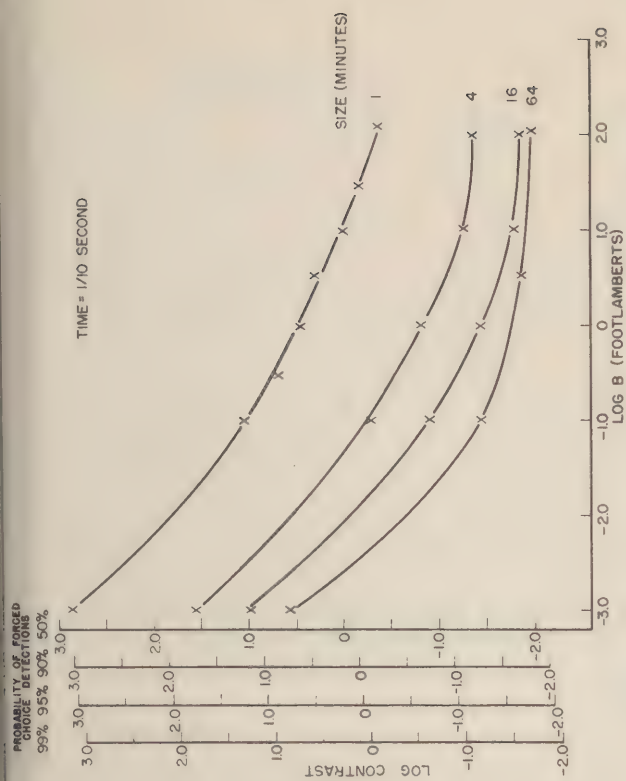


Figure 4. Data obtained with a time of exposure of 1/10 second. Each point represents at least 500 responses by two observers.

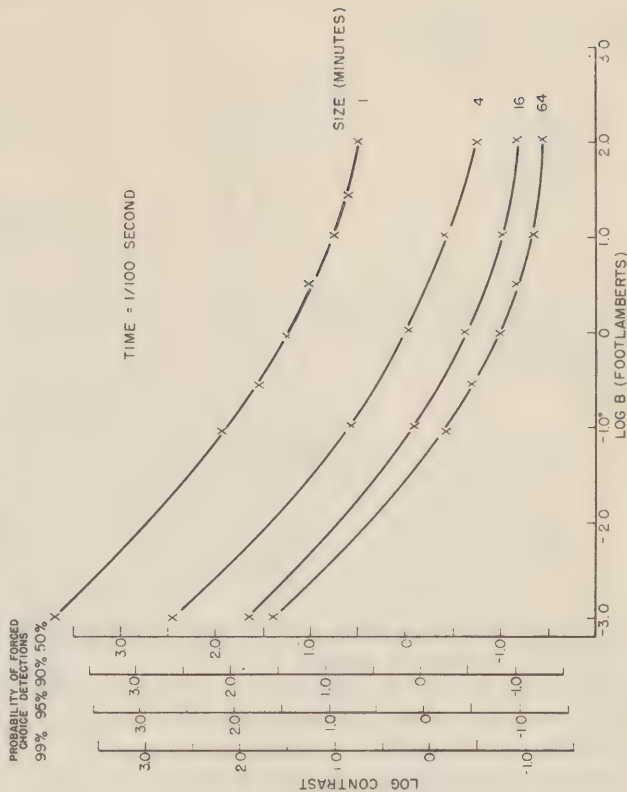


Figure 6. Data obtained with a time of exposure of 1/100 second. Each point represents at least 500 responses by two observers.

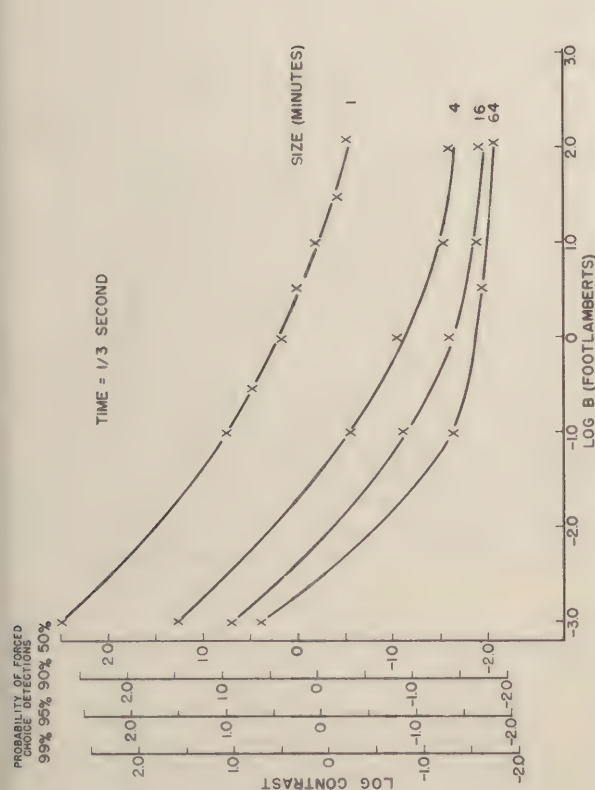


Figure 3. Data obtained with a time of exposure of 1/3 second. Each point represents at least 500 responses by two observers.

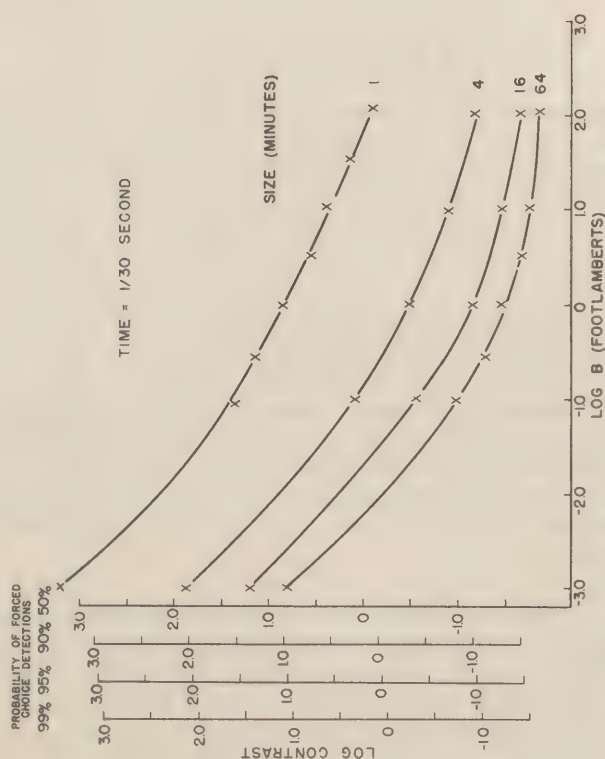


Figure 5. Data obtained with a time of exposure of 1/30 second. Each point represents at least 500 responses by two observers.

We may tabulate values of f_a once for all as follows:

f_a	probability of detection
1.29	.90
1.65	.95
2.33	.99

If we assume $\sigma/M = .390$, as in Figure 1, values of Z are as follows:

Z	probability of detection
1.50	.90
1.64	.95
1.91	.99

This means that, when $\sigma/M = .390$, a value of target contrast 1.50 times M , the threshold, will give 90% probability of detection; 1.64 times M will give 95%; and 1.91 times M will give 99%. (These values may be verified by inspection of Figure 1, where $M = 1$.)

We may inquire to what extent values of Z vary for experiments conducted at different values of the three experimental values. Values of Z for 99% detection probability are tabulated in Table 2, based upon values of σ/M presented in Table 1 and equation (3).

Values of Z vary among the four sizes by only $\pm 2.5\%$; among the eight luminances by only $\pm 4\%$; and among the seven durations by $\pm 10\%$. Variations in Z for probability levels less than 99% will vary less. It is concluded that variations in Z as a function of either size or background luminance are negligible. Variations in Z as a function of target duration are small, but should be allowed for in dealing with the present experimental data.

Insofar as Z is a constant multiplier times every value of M , we may represent different probabilities of detection by different scales of log target contrast, displaced by a constant amount representing $\log Z$. In Figures 2-8, the four ordinates have been computed by allowing for Z in this way. Each figure has been constructed with different values of Z , representing the fact that Z is not constant for different target durations. Within each figure, the same values of Z apply since we concluded that Z does not vary significantly as a function of either size or background brightness.

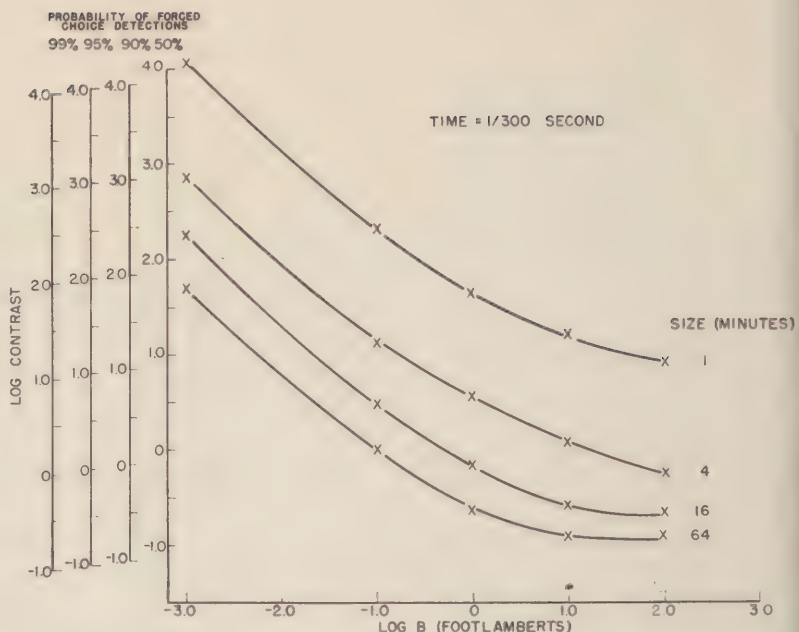


Figure 7. Data obtained with a time of exposure of 1/300 second. Each point represents at least 500 responses by two observers.

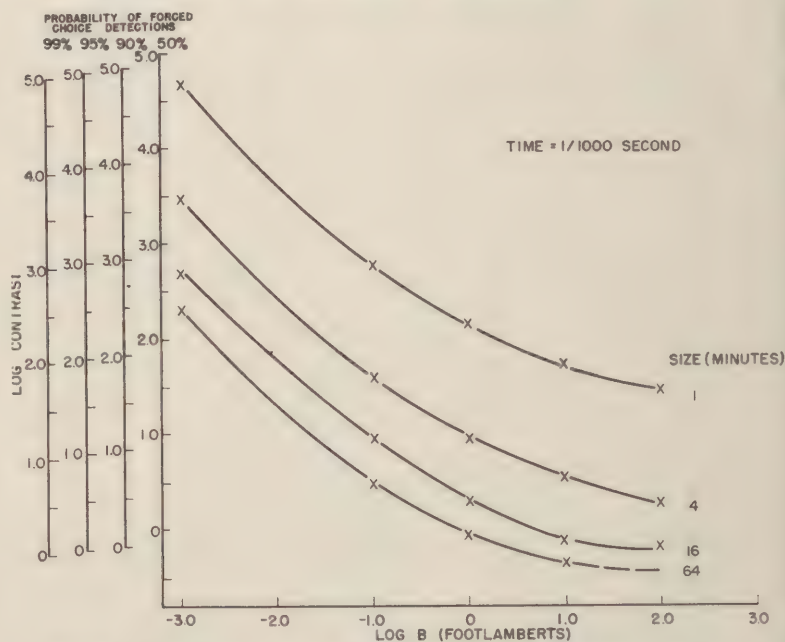


Figure 8. Data obtained with a time of exposure of 1/1000 second. Each point represents at least 500 responses by two observers.

Table 2: Values of Z

Target Size (minutes of arc)

<u>1</u>	<u>4</u>	<u>16</u>	<u>64</u>
1.87	1.97	1.92	1.90

B (foot-Lamberts)

<u>.001</u>	<u>.1</u>	<u>.3</u>	<u>1</u>	<u>3</u>	<u>10</u>	<u>30</u>	<u>100</u>
1.98	1.98	1.91	1.90	1.90	1.88	1.87	1.83

Duration (seconds)

<u>1</u>	<u>1/3</u>	<u>1/10</u>	<u>1/30</u>	<u>1/100</u>	<u>1/300</u>	<u>1/1000</u>
2.13	2.05	1.87	1.86	1.84	1.84	1.77

These experimental data should prove useful in making visibility predictions for situations in which the target falls within the foveal visual field.

Discussion:

Mr. Breckenridge asked if it would be possible for Dr. Blackwell to extend his measurements to extremely short exposures. Mr. Breckenridge stated that there was considerable practical interest in the relative effectiveness of light sources giving off very short pulses of light as compared with the more conventional sources.

Mr. Breckenridge also asked Dr. Blackwell to comment on the relation between his results and those of Blondel and Rey.

Dr. Blackwell commented that his apparatus would not be useful for extending the work to exposure durations much shorter than 1/1000 second, since the onset time for the flashes was 1/10,000 second. Dr. Blackwell went on to say that the Blondel and Rey experiments involved repeated flashes, whereas the present study involved single flashes. In the reports of the Blondel and Rey experiments, it is not clear whether the subjects were responding to single flashes or to trains of flashes. A further important difference between the two experiments is that Blondel and Rey were measuring the apparent brightness of a light source far above threshold, whereas the present experiments involve threshold brightnesses. In spite of all these differences, there is crude agreement between the two experiments. Both agree in showing that at very short exposures, time and intensity are reciprocal. At longer exposures, the departure of the present data from the Blondel-Rey law is considerable.

THE FIELD OF VISION AND ITS SIGNIFICANCE WHEN PROJECTED INTO SPACE

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Clement McCulloch, M. D.

INTRODUCTION

The detection of an aircraft in flight, whether from the ground or the air, is not always easy. Apparently there are certain limitations, both in the ability of the eye to see, and in the physical characteristics of the task to which the eye is put, which define when an aircraft can be seen. These limiting factors may be divided into:

- (a) Physical Factors - related to, the object
the background
the transmission of the atmosphere - special
conditions such as fog, haze
relative motion of the object.
- (b) Time - the time which is available for viewing.
- (c) Physiological Factors - visual acuity
fields of vision
the state of visual adaptation
aberrations of vision - spasm of accommodation
refractive errors

In this paper only one part of the problem is considered, that is, the fields of vision. We have done fields of vision for different brightnesses, different contrasts, and different sizes of test objects. The results of this work have been recalculated, assuming that the size of the test object remains constant but that the working distance varies. The figures so obtained represent the field of vision for a given standard object viewed at all possible distances away from the observer. When calculated in this manner the fields of vision look entirely different to those commonly presented in the text-books. These new limits are allied to reality, because they do represent breadth of vision for an object, such as an aircraft, at all distances from the observer.

Laboratory Procedures

These consisted of doing fields of vision on a tangent screen, in much the same manner as they are done clinically. Dark test objects were used against a white background. The working distances varied from 2000 to 10,000 mm., the brightness of the screen from 6 to 822 foot-candles.

Physical Set-Up

The work was done in a large room; about 25 feet wide, 50 feet long, 15 feet high.

The room had previously been used for night vision testing, the walls were painted black. At one end of the room was a large mat-white screen fastened to the wall. The screen was about 10 feet high and 15 feet across, and had a reflectance of 80.85%. The fixation object was a thumb tack one centimeter across, painted white, with a black cross at its centre joining a black circle at its outer edge. This object was affixed at the centre of the white screen. Intervals of 10 centimeters were marked from here to the periphery of the screen, by very small pencil marks. The subject sat facing the screen with his back to the room, on a platform so raised that his chair was three feet off the ground. A chin rest was not used; however, the subject's head was fixed in a rest coming from the back of the chair. The test objects were Munsell neutral papers, ranging from number 5 to number 9 values. These were made into round, flat objects, varying from 2 to 10 mm. in diameter and mounted on fine white rods. The lighting was obtained from diffuse reflectors set on either side of the subject. The number and the power of the lamps which were used varied according to the illumination which was desired. The colour temperature of the lamps was not the same for all levels of illumination. Sixty watt tungsten lamps were used at 6 lamberts, 150 watt lamps at 20 lamberts, and photoflood bulbs at the high brightnesses. The lights of the room were turned out.

Photometry

Two instruments were used for the photometry, the photometer (Model 520M) of the Photovolt Corporation and the Macbeth Illuminometer. Comparable readings were obtained with the two instruments. However, our Photovolt photometer was showing drift, and did not present a perfect linear relationship between the different scales. We were not satisfied with the readings from it and therefore discarded all readings from that instrument in favour of those from the Macbeth Illuminometer. With the Macbeth instrument for each illumination we took readings at seven positions on the screen; straight ahead, right, left, upper right, lower right, upper left, lower left. Ten readings were taken for each location, five from each direction on the scale of the instrument. To obtain the brightness of the screen we accepted the reflectance given by the Munsell Corporation for one of their neutral papers. We then compared the brightness of the screen against the brightness of the Munsell paper, using one of our levels of illumination and calculated the reflectance and the brightness of the screen. The reflectances of the test objects were found similarly by comparing them with the Munsell neutral paper. The figures obtained checked closely with the reflectances submitted by the Munsell Corporation for other neutral papers.

Technique of Testing

A limited number of subjects were used, ten in all. All the subjects had 20/20, or 20/30, visual acuity in either eye. All the subjects did not work at each level illumination, although most of them worked at several levels. The results of the tests were not used until the subjects had undergone one or more practice sessions. Each session consisted of approximately 30 minutes. The duration of the sessions was limited because after longer periods the subjects became tired and the results wandered. A shield with a pad was placed over one eye. The subject sat in the chair with his head against the back rest from the chair. The examiner wore a white coat. The subject fixed on the central fixation object. The examiner moved the test object in from the side of the screen at an approximately constant rate of 10 cms. per second, without jiggling the test object. When the subject first saw the object he said "yes." The examiner recorded the distance and the subject wrote the distance on a piece of paper on his lap. The findings in 12 meridians were recorded, that is, every 30 degrees. Five subjects were used at each illumination, except at the highest and at the lowest illuminations where three subjects were used. At each level of illumination each subject completed one reading for all the sizes of test objects, for all the brightnesses of test objects, and for all the meridians. The standard working distance was 2,000 mm. However, it was found that when test objects smaller than 2 mm.

were used the rod could be a guide to the test object. Therefore, the smaller sized objects were replaced by larger objects and working distances up to 10,000 mm.

Results

The following table gives the reflectance of the screen, the reflectances of the test objects, and the contrast between the screen and the test objects. The contrasts were calculated according to the formula $C_o = \frac{B_t - B_o}{B_o}$

C_o = inherent contrast
 B_t = brightness of target
 B_o = brightness of background

Reflectance of Screen	Reflectance of Object	Contrast
80.85%	16.75%	-0.79
"	29.60%	-0.63
"	44.24%	-0.45
"	53.08%	-0.34
"	72.97%	-0.097

The radii of the visual fields were averaged for each size, for each contrast, and for each illumination. When working distances greater than 2000 mm. were used the radii of the visual fields were reduced to correspond to the shorter working distance. The following table gives the radii of the visual fields, in centimetres, for a working distance of 2000 mm. for each size of test object and for each contrast.

TABLE I

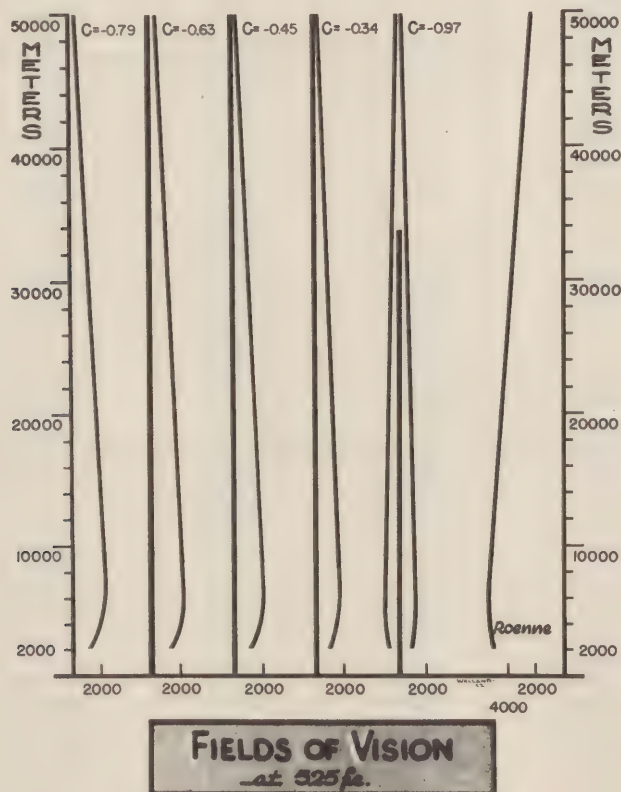
Illumination	Diameter of Object	C = -0.79	C = -0.63	C = -0.45	C = -0.34	C = -0.097
6 foot-candles	10 mm	118 cm.	110	99	90	53
	9 "					
	8 "	106	97	88	75	45
	7 "					
	6 "	89	81	75	55	36
	5 "					
	4 "	66	65	62	40	28
	3 "	45	41	36	22	16
	2 "	33	29	28	11	12
	1 "	14	10	9	6	4
	4/5 "	6.4	4.4	3.6	2.2	1
	3/5 "	4.8	3.0	1.8	1.2	
	2/5 "	0.6	0.4	0.2		
20 foot-candles	10 "	128	120	115	106	73
	9 "	123	117	111	97	65
	8 "	118	111	104	93	63
	7 "	113	104	99	88	58
	6 "	101	95	96	84	51
	5 "	92	89	86	76	47
	4 "	85	81	81	66	42
	3 "	51	51	45	39	23
	2 "	38	39	36	30	19
	1 "	18	15	16	12	9
	4/5 "	5.4	5.2	4.4	2.6	0.6
	3/5 "	3.8	3.0	2.0	0.8	
	2/5 "	1.6	0.8			
110 foot-candles	10 "	128	123	114	93	65
	9 "	127	118	104	84	53
	8 "	124	112	98	81	52
	7 "	113	105	92	78	49
	6 "	108	100	90	71	41
	5 "	94	93	82	62	34
	4 "	84	82	76	55	34
	3 "	54	54	49	36	20
	2 "	41	41	37	26	16
	1 "	20	15	17	12	8
	4/5 "	8.8	7.6	6.8	4	0.8
	3/5 "	6.8	5.4	4.6	2.4	0.4
	2/5 "	1.2	1.1	0.8	0.4	0.2

TABLE I (continued)

Screen Brightness	Diameter of Object	C= -0.79	C= -0.63	C= -0.45	C= -0.34	C= -0.097
225 foot-candles	10 mm.	128 cm.	126	121	107	70
	9 "					
	8 "	120	117	107	94	59
	7 "					
	6 "	101	98	90	71	43
	5 "					
	4 "	85	80	77	53	33
	3 "	53	51	46	32	20
	2 "	41	38	33	20	14
	1 "	16	11	11	9	6
	4/5 "	6.6	3.6	3.4	2.6	1.2
	3/5 "	3.2	2.6	2.2	1.8	0.6
	2/5 "	1	0.8	0.8	0.6	0.1
525 foot-candles	10 mm.	135	129	121	112	80
	9 "					
	8 "	125	121	111	102	69
	7 "					
	6 "	109	106	97	81	59
	5 "					
	4 "	92	82	86	67	49
	3 "	61	58	55	43	25
	2 "	45	43	45	32	18
	1 "	20	16	15	12	8
	4/5 "	10	7.6	6.6	4.2	2.6
	3/5 "	7.4	5.6	4.0	3.6	0.8
	2/5 "	1.4	1.0	0.8	0.8	0.4
822 foot-candles	10 mm.	139	128	122	103	79
	9 "					
	8 "	125	118	112	91	74
	7 "					
	6 "	115	106	98	76	55
	5 "					
	4 "	93	87	86	67	51
	3 "	59	58	55	42	26
	2 "	48	42	47	32	20
	1 "	21	14	15	10	8
	4/5 "	10	7.4	6.4	3.6	1.6
	3/5 "	8	5.4	4.4	2.8	0.4
	2/5 "	2.2	1.0	0.8	0.4	

Analysis

The authors' particular interest is not various sized test objects at a given distance but rather a given sized test object at various distances. To re-arrange our data we assume that the 10 mm. test object is our standard sized object seen at 2000 mm. and that the smaller sized objects merely represent a 10 mm. object seen at a greater distance; that is, a 5 mm. object would be equivalent to a 10 mm. object seen at 4000 mm., a 2 mm. object would be equivalent to a 10 mm. object seen at 10,000 mm; a 0.4 mm. test object would be equivalent to a 10 mm. object seen at 50,000 mm. For each of these longer viewing distances the radii of the visual fields are correspondingly increased, for example, for a viewing distance of 4000 mm. the radii are doubled. Because we are particularly interested in aircraft all distances are multiplied by 1000. We discuss metres instead of millimetres. The following tables show all the figures converted to a standard test object, 10 metres in diameter, viewed at distances starting from 2000 metres. The subsequent graph presents a sample of these figures, drawn to scale, with data from Roenne added (1). (Graph 1.)



Graph 1.

The above analysis has been on the basis of a round object 10 metres in diameter, or having an area of 78.5 square metres. To develop figures for any given aircraft we can follow the procedure of calculating areas (4). For any chosen aspect the total visible area of the aircraft is found. The peculiar shape of the aircraft is disregarded. The object is assumed to be round, having the area already discovered. The diameter of such a round figure is calculated and this diameter is compared with an object having a diameter of 10 metres. The brightness of the sky, and the brightness of the surface of the aircraft must be known. The contrast between sky and aircraft can be calculated. This contrast

TABLE II

Illumination	Position in Space	C= -0.79	C= -0.63	C= -0.45	C= -0.34	C= -0.097
6 foot-candles	2000M.	1180	1100	990	900	530
	2222					
	2500	1320	1208	1096	935	561
	2857					
	3333	1473	1347	1248	916	599
	4000					
	5000	1650	1625	1550	1000	700
	6666	1497	1364	1198	732	533
	10000	1650	1450	1400	550	600
	20000	1400	1000	900	600	400
	25000	800	550	450	276	126
	33000	800	500	300	200	
	50000	150	100	50		
20 foot-candles	2000M.	1280	1200	1150	1060	730
	2222	1364	1297	1231	1076	721
	2500	1470	1383	1296	1158	785
	2857	1613	1483	1412	1256	827
	3333	1680	1581	1597	1397	848
	4000	1838	1796	1746	1520	939
	5000	2126	2026	2026	1650	1050
	6666	1697	1697	1497	1297	765
	10000	1900	1950	1800	1500	950
	20000	1800	1500	1600	1200	900
	25000	676	650	550	325	76
	33000	634	500	334	134	
	50000	40	20			
110 foot-candles	2000	1280	1230	1140	930	650
	2222	1408	1309	1154	932	588
	2500	1544	1395	1221	1010	647
	2857	1613	1499	1313	1114	699
	3333	1796	1663	1497	1181	682
	4000	1879	1859	1636	1240	680
	5000	2100	2050	1900	1375	850
	6666	1796	1796	1630	1198	665
	10000	2050	2050	1850	1300	800
	20000	2000	1500	1700	1200	800
	25000	1100	950	850	500	100
	33000	1133	899	766	400	66
	50000	300	275	200	100	50

TABLE II (continued)

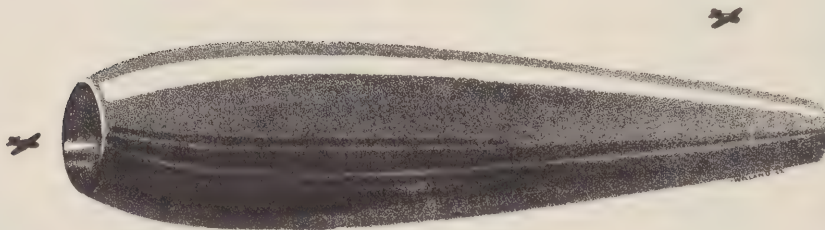
Illumination	Position in Space	C= -0.79	C= -0.63	C= -0.45	C= -0.34	C= -0.097
225 foot-candles	2000M.	1280	1260	1210	1070	700
	2222					
	2500	1494	1457	1333	1170	740
	2587					
	3333	1680	1630	1497	1181	715
	4000					
	5000	2125	2000	1925	1325	825
	6666	1764	1697	1531	1065	665
	10000	2050	1900	1650	1082	700
	20000	1600	1100	1100	900	600
	25000	825	450	425	325	150
	33000	560	433	366	300	100
	50000	250	200	200	150	26
525 foot-candles	2000	1350	1290	1210	1120	800
	2222					
	2500	1557	1507	1383	1270	860
	2587					
	3333	1814	1764	1614	1347	982
	4000					
	5000	2300	2051	2150	1675	1225
	6666	2030	1930	1830	1431	832
	10000	2250	2150	2250	1600	900
	20000	2000	1600	1500	1200	800
	25000	1250	950	734	525	325
	33000	1233	933	575	600	134
	50000	350	250	200	200	100
822 foot-candles	2000	1390	1280	1220	1030	790
	2222					
	2500	1557	1470	1395	1134	922
	2587					
	3333	1914	1764	1630	1265	915
	4000					
	5000	2325	2175	2150	1667	1275
	6666	1963	1930	1830	1397	865
	10000	2400	2100	2350	1600	1000
	20000	2100	1400	1500	1000	800
	25000	1275	925	800	450	200
	33000	1333	899	733	466	66
	50000	550	250	200	100	

must be corrected for attenuation by the atmosphere. After making these adjustments for size of object, contrast, and attenuation of contrast, the figures in Table II can be used to calculate the area in the sky, or the limits in space, where the aircraft is visible at a single glance. The needle-like shape of the figures will remain, the width and length will merely vary according to the circumstances.

Discussion:

These limits of vision for any one instant do not look like the visual fields seen in the text-books. When portrayed as different sized objects at a constant working distance the limits of vision make a mushroom-shaped figure (1-3). However, when depicted as a constant object seen at varying distances the limits of vision become a needle-like figure reaching far out into space. This last presentation is more in keeping with reality, where we commonly see an object of a given size at various distances.

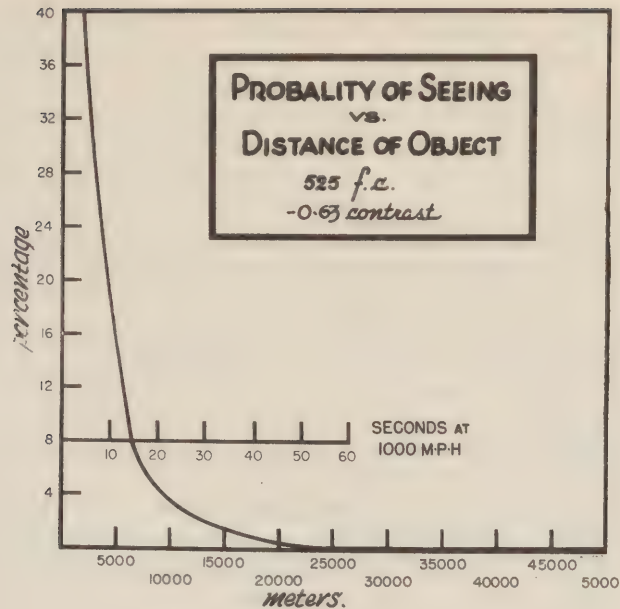
This needle-like figure dramatically illustrates how difficult it is to pick up an aircraft in the distance (Graph 2). The observer is indeed looking for a needle in a hay-



Graph 2.

stack. Compared with the total area of sky the area which is available at any one instant is minute. As an example, let us assume an observer is searching for an aircraft having an area of 78.5 square metres. The brightness of the sky is about 500 lamberts. Supposing the observer is searching in one-quarter of the sky, that is, from straight ahead to above, and to 90 degrees on either side. Let us assume that the contrast between the aircraft and the sky is -0.63. At 25,000 metres the area of sky in which the craft would be visible is 2,800,000 square metres. The total area of sky in which he is searching is 1,900,000,000 square metres. His chances of seeing the aircraft at any one instant would be the area of field over the area of search, which is 0.15 per cent. In comparison, at 5,000 metres the total area of the sky in which the aircraft would be visible is 78,000,000 square metres, the total area of the sky in which he is searching is 12,000,000 square metres, and his chances of seeing it are 16 percent. The following chart shows distance against chances of seeing for this particular set of conditions. (Graph 3.)

Not only do the limits of vision take on this peculiar configuration in space but they also can be differentiated with regard to time. If the time available for search is small the possibility of detection at the greater working distances remain low. However, if the



Graph 3.

time available for search is unlimited the possibility of detection at the greater working distances would be good. When viewing one aircraft from another aircraft the time available is short, and as aircraft become faster, the time is going to be even shorter. With greater speeds the limits of the fields of vision will become increasingly critical factors until vision is finally replaced by electronic control. To illustrate the factor of time in these graphs seconds at 1000 miles per hour has been included in Graph No. 3. It can be seen that the range in seconds in which the limits of vision are wide, and the probability of seeing is high, is very short, in fact only a few seconds. Over many more seconds the aircraft is visible but the probability of seeing is low.

The graphs illustrate the fact that there is an optimum range for efficient detection. This optimum range is obviously at the distance where the limits of vision widen out and the probability of seeing rapidly increases. But the other dimension, time, is equally important. As the time available for search increases the optimum range for efficient detection can be extended. As the time for search decreases the optimum range for efficient detection must shrink back towards the region where the visual fields expand and the probability of seeing increases. From a practical point of view, discussing aircraft against aircraft, when the range for efficient detection shrinks to the point where the pilot no longer has a chance to manoeuvre, mechanical aids for search, and for control of the aircraft, are an absolute necessity.

These limits of field were surprisingly constant for the different levels of illumination which we used. Also, with changes in contrast the size of the field varied but the shape of the field remained essentially unaltered. Apparently, the broad conclusions which might be drawn from the figures apply over a great range of brightnesses and of contrasts. However, it is worth noting that both with increased brightness and with increased contrast the limits of vision expanded.

Inadequacies of the Experiment

There are a number of inadequacies to this work which occur in the physical set-up,

the testing procedures, and the analysis of the results. These indicate that the work could be done better and that the results might be more exact; but they do not seem to detract from the overall conclusions. The accuracy of the photometry is set by the accuracy of our work with the Macbeth Illuminometer. The results checked fairly closely with those obtained by the Photovolt photometer. The lighting was obtained by floodlights. This system resulted in high-lights on the screen. When fewer bulbs were used this variation in brightness reached 50 percent, when more bulbs were used the variation was less. In view of the fact that the changes in the limits of vision with increasing brightness were not great the error produced by highlights on the screen is probably not important. The rods used for carrying the test objects were visible. They were small rods painted the same colour as the screen, held close to the screen so that they did not cast a shadow. By trial it was found that when large test objects were used the rod was not noticed by the observer but when small objects were used the rod became of importance. We therefore used larger test objects at greater working distances and calculated the equivalent sizes at the shorter distance. Similarly, although it was not visible to the observers, the rod was probably the source of appreciable error when testing at the lower contrasts. The mode of testing might be called clinical rather than scientific. The test object was brought in by hand at approximately a certain speed. The end point was checked from the invisible toward the visible and not from the visible toward the invisible; only one reading was taken on each meridian. The readings for all the meridians and for all the observers were averaged. This assumes that the field of vision is approximately a circle; which is probably right for small test objects but is in some error for large test objects. However, from a practical viewpoint, it does not seem worthwhile bothering about this meridional shape to the limits of vision. No field trials were done. We had planned to construct a grid, from wires, have aircraft pass over the roof of our building and estimate their field of visibility. Because of this lack of field trials correcting factors for reality are not known. We have completely neglected the Aubert-Forster effect (5). This effect suggests that at different working distances the fields of vision are not comparable. Glees and Frohlich found that this effect does not occur. (6). Our data could be extended to greater contrasts, higher and lower brightnesses, and to light objects on dark backgrounds.

The present work attacks only one aspect of the problem of visibility of aircraft. It is intended to fit in with other data which is available, or may become available, such as: sky brightness, aircraft reflectance, illumination from the sun, atmospheric attenuation, experience from the effect of mist, smog, angular movement and anoxia.

Summary

The fields of vision of dark test objects on a white background have been done for different sizes of test objects, different contrasts between object and background, and different quantities of illumination. This data has been calculated assuming a constant size object but at different working distances. The fields so obtained are long needle-like figures whose shapes indicate the low probability of seeing a small object in the distance. This low probability of seeing particularly applies when considering aircraft flying at high speed.

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5. Aubert, H. and Forster, R. Arch. f. Ophth. 3: II. 1-68. 1857.
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Discussion:

- Dr. Blackwell expressed considerable interest in Capt. McCulloch's work. He noted that Dr. Lamar had reported several years ago on probability of detection as a function of position in the visual field. The Lamar report consisted of probability lobes representing the threshold target distance for targets located in various portions of the visual field of the observer. When the observer moved his eyes, the lobe moved with the eye. It is possible to compute a combined probability lobe representing a particular scan pattern.
- Dr. Blackwell commented that Capt. McCulloch's work represented the static case, in which the eye was directed in a single direction. He suggested that Capt. McCulloch might wish to compare his results with those presented in the Lamar study.
- Dr. Blackwell questioned the use of the term probability to refer to Capt. McCulloch's results. Presumably one can compute probability contours only if one obtains frequency-of-seeing data. Dr. Blackwell expressed his understanding that Capt. McCulloch had actually determined only a threshold end point in using his technique of clinical perimetry.
- Group Capt. McCulloch agreed with Dr. Blackwell that his graph represented seeing only at one instance and that in most instances the cone would "scan" the sky.

CHARACTERISTICS OF TANK-MOUNTED SEARCHLIGHTS FOR DETECTION OF GROUND TARGETS

H. Richard Blackwell, S. Q. Duntley, and Wilfred M. Kincaid

INTRODUCTION

The detection of military ground targets at night is difficult to accomplish at satisfactorily short ranges. One method of aiding detection is to provide auxiliary illumination of the ground targets with a searchlight. The present report describes a method for determining the searchlight candlepowers required for detection of specified ground targets, and reports a number of calculations made with this method.

The situation of interest involves a tank-mounted searchlight used to aid the detection of enemy tanks by gunners in the tank bearing the searchlight, and by gunners in other tanks deployed in the near vicinity. The enemy tank may be silhouetted against the sky or against terrain varying in reflectance. The gunner may attempt to detect the tank with the unaided eye, or he may use optical magnification. It is required that the gunners detect the enemy tank at a range of 1200 yards under some conditions, 1500 yards under other conditions. The searchlight will be turned on for short periods only, so that the gunner has only a few seconds at most to examine the area illuminated by the searchlight for possible enemy tanks.

The situation is illustrated schematically in Figure 1. The eye of the gunner, O, is directed at the target, T, situated against the background, B. Both the target and the background are illuminated by the searchlight, P, and some fraction of the illuminance is reflected in the direction of the eye of the observer. The inherent luminances of the target and background, i.e., the luminances at the target and background, are the products of the illuminance falling upon them and their reflectances. The apparent luminances of target and background are the luminances at the observer's eye. Apparent luminances differ from inherent luminances due to the effects of the atmosphere.

VISUAL DETECTION DATA

The ability of the eye to detect a target depends primarily upon (a) B_T , the apparent luminance of the target; (b) B_B , the apparent luminance of the background; and (c) α , the angular subtense of the target at the eye. Other factors such as target shape, and target and background color, are of secondary importance and may be ignored for the present purposes.

Rather than describing a target in terms of α , B_B , and B_T , it is equally valid and more convenient to describe it in terms of α , B_B and the ratio

$$(1) \quad C = \frac{B_T - B_B}{B_B},$$

which is called the contrast between target and background. (Apparent contrast is defined at the eye, inherent contrast at the target.)

The roles of α , B_B and B_T in target detectability may be evaluated from the laboratory studies of visual detection reported by Blackwell.¹ These data were gathered by

¹H.R. Blackwell. *Illus. Engr.*, 47, 602-609 (1952).

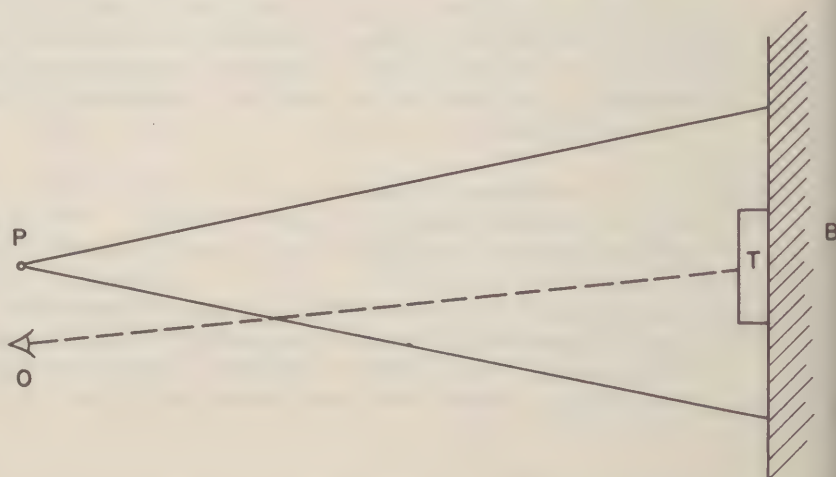


Figure 1: Schematic Diagram.

having observers look at a screen on which circular spots of light, the targets, were projected from time to time in a fixed known location. The background luminance, angular size of target, and duration of target were fixed during each observing session. A procedure was utilized in which the observers had to prove they detected the presence of the target by correctly identifying when it appeared, given a choice of four successive time intervals. It should be emphasized that the observers had merely to detect the presence of the target, not to identify its shape, color or other such attribute. Since the observers were required to guess when they were uncertain, the procedure is called forced choice. Each experiment involved determining the probability of forced-choice detection for each of a number of target contrasts. It is found that the probability of detection increases from zero to 100% as target contrast is increased. It is possible to analyze detection data to ascertain the target contrast which will be just detectable at any pre-assigned level of probability. The experiment was repeated for a number of values of background luminance, target size, and target duration.

The curves of Figure 2, taken from Blackwell, show the contrast required (ordinate) for 99% forced-choice detections as a function of the background luminance (abscissa). Target subtense, α , is the parameter. We note that the required contrast decreases as B_B increases. As we shall see, this is the reason it is advantageous to illuminate targets with searchlights. The figure also shows that the contrast necessary for detection decreases as the angular subtense of the target is increased. This indicates that it is an advantage to use optical magnification.

The data in Figure 2 represent target durations of 1 second. It appears from other data that the curves are much the same for all durations greater than 1 second. Since the tank gunners should have at least one second to look for a target under field conditions, data representing one-second target duration were considered appropriate for use in the present case.

We have noted above that the probability of forced-choice detection varies with target contrast. It might seem reasonable to require 100% detections in military problems. It is meaningless to make this requirement, however, since there are no conditions under which we can say that misses will never occur. We have selected Blackwell's data representing 99% probability of forced-choice detections as a practical level.

We may wonder to what extent laboratory data such as those plotted in Figure 2 apply to a field situation. It has been shown elsewhere² that laboratory thresholds are equivalent to field thresholds obtained under the same conditions of measurement. Hence, the data of Figure 2 apply to field detections made by forced choice, under conditions in which the observer knows when and where to expect the target, and in which he is able to devote full attention to the task of visual detection. In our problem, the gunner knows

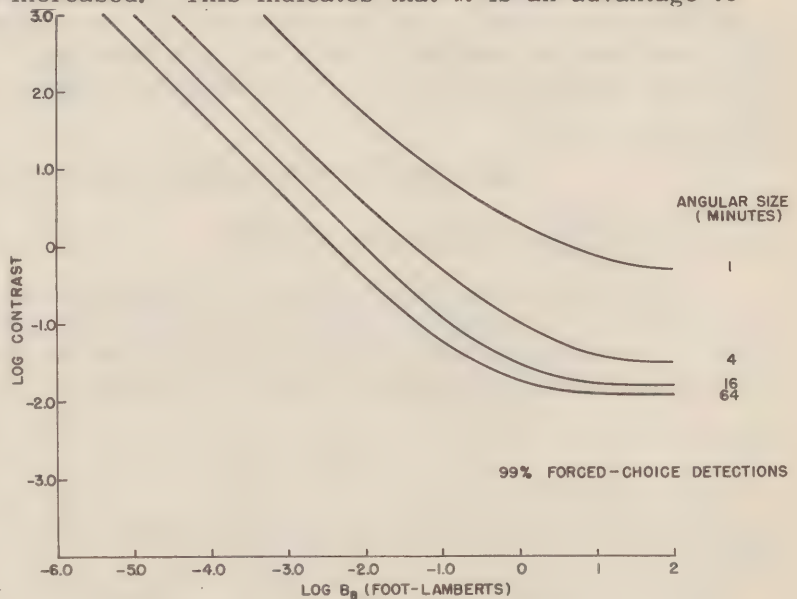


Figure 2: Laboratory Visual Detection Data.

²H.R. Blackwell, B.S. Pritchard, and J.G. Ohmart. *Field Tests of Visibility and Atmospheric Optics.* (In press.)

when and approximately where to expect the target to appear. The gunner presumably devotes full attention to the task of visual detection, since the searchlight is turned on for brief periods only.

The gunner does not, of course, make forced-choice detections. It is shown elsewhere³ that forced-choice detections occur at lower target contrasts than detections based upon a simple awareness of the presence of the target. The factor relating the contrast required for a given probability of awareness to the same probability of forced-choice detections has been shown to vary between 1.20 and 2.40. The value of this factor depends upon the extent to which observers employ all cues available for visual detection when making responses of awareness. Observers making their first visual detections use comparatively few of the available cues, and hence the factor is as large as 2.40. Observers with extensive laboratory experience learn to use more cues and reduce the value of the factor to 1.20. It is not certain to what extent military observers use all available cues when detecting targets in the field situation. We believe they probably have learned to use more of these than observers making their first detections, but less than observers with extensive laboratory experience. We believe that a factor of 2.00 is probably conservatively large. Thus, alternative use of the curves of Figure 2 and of curves constructed by doubling the threshold contrast should set reasonable limits of the best and worst detections to be expected in the field.

The data in Figure 2 are based upon two observers only. Military personnel will vary considerably in their visual detection ability. We believe that few, if any, military personnel will have greater detection ability than our observers. Thus, use of these data will provide minimum candlepower values for the required visual detections.

METHOD OF SPECIFYING SEARCHLIGHT INTENSITIES

Case of Negligible Atmospheric Effects

It will prove simplest to begin by developing a method of predicting required searchlight intensities in the absence of light scattering by the atmosphere. If I is the intensity of the light, D the distance from the searchlight to the target, and R_B and R_T are the respective reflectances of background and target, we have in accordance with the inverse square law

$$(2) \quad B_B = \frac{IR_B}{D^2}, \quad B_T = \frac{IR_T}{D^2}$$

(provided the beam is normally incident upon the target, as we shall assume henceforth). Thus we have

$$(3) \quad C = \frac{R_T - R_B}{R_B}$$

Consider, for example, a tank of reflectance .08 viewed against a background of reflectance .06. The contrast by (3), is .333 and $\log_{10} C = -.48$.

Suppose the tank has a projected area of 60 square feet and is at a distance of 1200 yards from the observer's eye. A compact shape such as a tank may be assumed to have the same detection threshold as a circular disc of the same area. In this case, the equivalent circular disc has a diameter of 8.72 feet, which subtends an angle $\alpha = 8.32$ minutes at 1200 yards.

³H.R. Blackwell. *Psychophysical Thresholds: Experimental Studies of Methods of Measurement*. Eng. Res. Bull. No. 36 (University of Michigan, January 1953).

Referring to Figure 2, we see that the horizontal line $\log_{10} C = -.48$ intersects the curve for $\alpha = 4'$ at $\log B_B = -.80$, that for $\alpha = 16'$ at $\log B_B = -1.51$, and that for $\alpha = 64'$ at $\log B_B = 1.88$.¹⁰ Interpolating graphically, we conclude that for $\alpha = 8.32'$ we should have $\log B_B = -1.22$ or $B_B = .0602$ footlamberts. That is, a background luminance B_B of .0602 footlamberts is required to see the tank under these conditions.

To find how intense a searchlight would be required in the absence of atmospheric light scattering, we use equation (2). Since D is in yards we must first multiply B_B by 9 to convert it to yardlamberts. Substituting in (2), we obtain $I = 13 \times 10^6$ candles. Note that this is the required intensity of the portion of the searchlight beam that strikes the target. This is the minimum candlepower which will make the target detectable; greater candlepower would of course be desirable for a safety factor.

If the observer uses 10 power magnification, we have $\alpha = 83.2'$. For this value of α we conclude that $B_B = .0126$ footlamberts and $I = 2.7 \times 10^6$ candles. We note that the requisite candlepower is substantially reduced by having the observer use magnification. Attention should be called to our assumption that optical magnification has no effect except increasing the size of α . If the optical aid is mounted rigidly, is properly adjusted, and does not reduce apparent target contrast, our assumption will be justified. Any defects in the optical aid will result in higher required values of B_B and hence of searchlight intensity.

In the above computations, interpolation was necessary because the curves of Figure 2 did not correspond to the desired values of α . Since the same values of α are used in many subsequent computations, it is worthwhile to carry out the interpolation once and for all and construct curves from which the desired values can be read directly. Detection ranges of 1200 and 1500 yards are of interest; detections by the unaided eye, and with 6 and 10 power magnification are of interest at each detection range. The three desired curves for 1200 yards are plotted in Figure 3; the curves for 1500 yards are plotted in Figure 4.

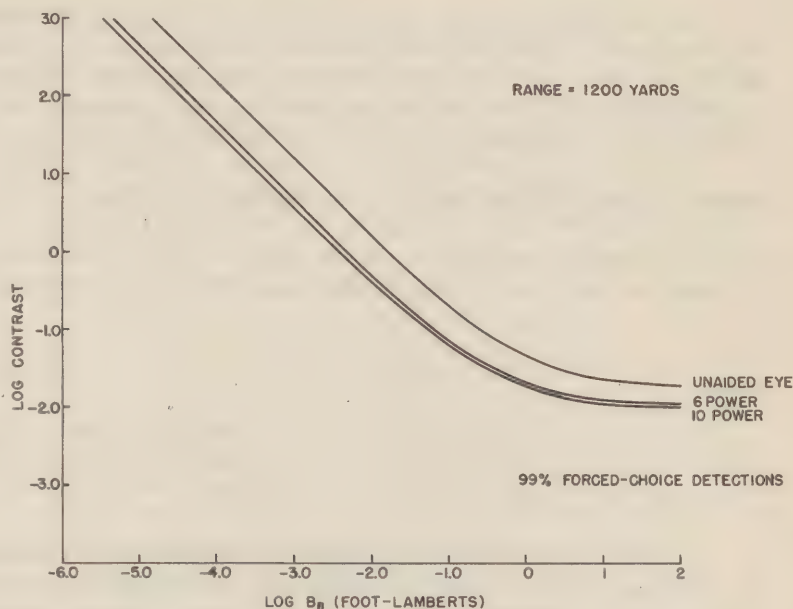


Figure 3: Interpolations from Laboratory Visual Detection Data.

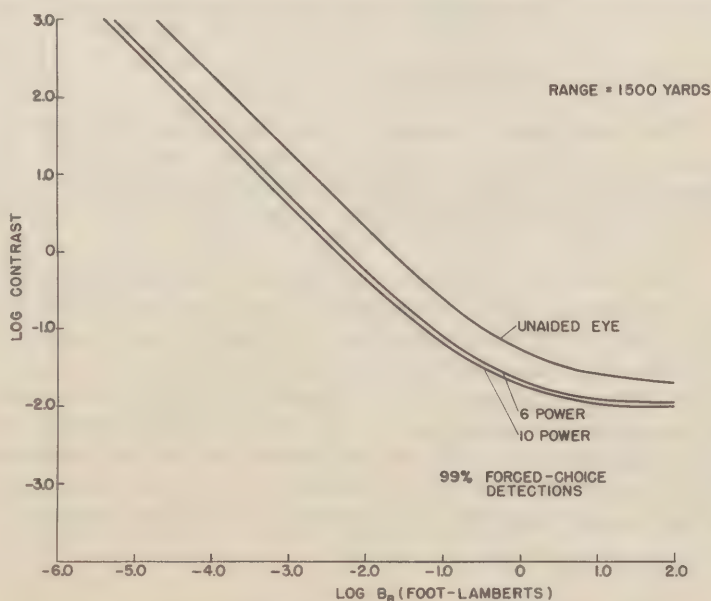


Figure 4: Interpolations from Laboratory Visual Detection Data.

Effects of Atmospheric Scattering

Up to now we have ignored the effects of the atmosphere. Due to its presence, scattering and absorption of light occur, to an extent which varies widely from time to time. Usually absorption is slight compared with scattering and it will be ignored in the present discussion.

Scattering has two effects we must consider. First, light that would otherwise illuminate the target is lost by scattering on the way. Second, some of the light from the beam is scattered back to the observer's eye and produces a veiling luminance over both target and background.

With regard to the first effect, the amount of light lost by scattering from a beam is proportional to the original intensity of the beam. Then if $1-t$ is the proportional loss in one yard, so that t is the proportion remaining, the proportion remaining after x yards is t^x . Light reflected from the target back to the observer's eye traverses a total distance $2D$; hence, the contribution to the apparent luminance B_T of the target by light reaching the observer's eye without having undergone scattering is $\frac{IR_T t^{2D}}{D^2}$.

We may modify equations (2) and (3) to allow for atmospheric effects. If S is the veiling luminance scattered back to the eyes from the direction of the target, we have

$$(4) \quad B_B = \frac{IR_B t^{2D}}{D^2} + S, \quad B_T = \frac{IR_T t^{2D}}{D^2} + S,$$

$$(5) \quad C = \frac{(R_T - R_B) t^{2D}}{R_B t^{2D} + \frac{D^2 S}{I}}.$$

As one would expect, scattering diminishes apparent contrast. Clearly it is necessary to determine S in order to determine the apparent contrast of a target of interest. As we shall see, S depends upon the beam spread of the searchlight, and upon the variations in intensity from point to point in the beam. We have assumed certain searchlight characteristics in making our calculations and it will be convenient to describe these at this point.

Searchlight Characteristics

We have made extensive use of a candlepower distribution reported by Hulburt⁴ and plotted in Figure 5. This distribution was measured on a Navy 36" searchlight. The distribution falls to 10% of the maximum intensity at an angular distance of 0.84° from the center, in any direction from the center.

The military requirement for the searchlight was that it should illuminate targets within an area having an 8° horizontal dimension and a 1° vertical dimension. We assumed that this might be accomplished with a searchlight having a light distribution similar to the Navy 36" light, but casting an elliptical instead of a circular beam. The candlepower distribution in the horizontal dimension follows the distribution shown in Figure 5 adjusted for scale so that the angular width out to the 10% intensity point is 4° on each side of the center; similarly, the angular width of the beam out to the 10% intensity point in the vertical dimension is 0.5° on each side of the center. In other directions, the distribution is the same, its angular width varying in accordance with the elliptical character of the beam.

⁴E.O. Hulburt. J. Opt. Soc. Am., 36, 483-491 (1946).

Calculation of the Veiling Luminance

When the observer looks at the target, he looks through a part of the searchlight beam as shown in Figure 1. Light scattered back to the observer's eye from the atmospheric particles in the searchlight beam produce a veiling luminance, S , which adds to the luminance of both the target and background. We may now develop a method for relating S to the distributional characteristics of the searchlight beam.

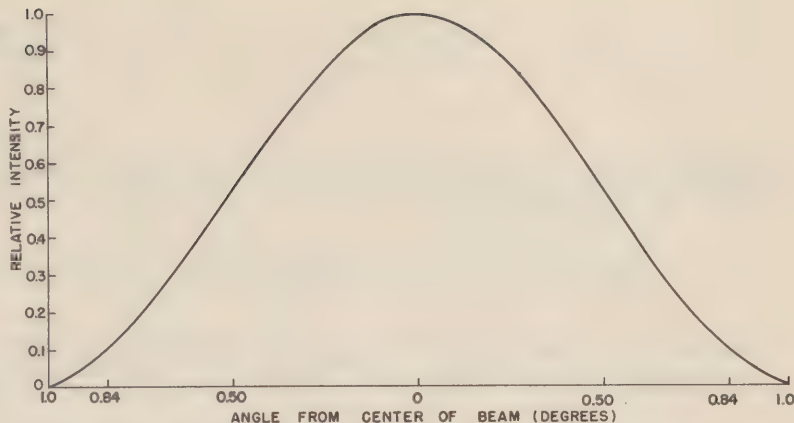


Figure 5: Standard Candlepower Distribution.

The searchlight illuminates all of the path of sight which lies within the searchlight beam. Let us consider a thin lamina of atmosphere perpendicular to the line of sight and located at a distance x from the observer. Let the thickness of the lamina be dx , and let the illuminance on the lamina by the searchlight be denoted by E . The resulting apparent luminance of the lamina as seen by the observer will be

$$(6) \quad dS = \sigma E t^x dx,$$

where the factor t^x represents the loss of light due to scattering throughout the path from the lamina to the eye of the observer. (No account is taken of rays entering the eye after multiple scattering, but this effect is probably negligible.) The proportionality constant σ in equation (6) is a scattering coefficient; it is defined by equation (6). Its value depends upon the direction in which the lamina is viewed. Hulburt (4) gives a polar curve of σ for typical country air. He shows that the value of σ is nearly the same for all light scattered in rearward directions. Since scattered light entering the observer's eye is of this character, this constancy of σ permits our computations to be much simpler than they otherwise would be.

A further simplification of the problem stems from the fact that the entire polar curve of σ is representative of most of the air masses likely to be encountered; hence the total scattering is proportional to the rearward scattering σ . Since the loss of light, as expressed by t^x , is due almost entirely to scattering, there is a fixed relation between t^x and σ .

It is convenient at this point to introduce the concept of meteorological range v , defined as the distance at which only 2 per cent of the original unscattered light remains in the beam of the searchlight. Thus t and v are related by the equation $t^v = .02$, and

$$v \ln t = \ln (.02) = -\ln 50 = -3.912$$

or

$$\ln t = \frac{-3.912}{v}$$

Hence $t^x = e^{\frac{-3.912}{v} x}$, and the proportional loss in a short distance dx is

$$\frac{t^x - t^{x+dx}}{t^x} = 1 - t^{dx} = 1 - e^{-\frac{3.912}{v} dx} = \frac{3.912}{v} dx.$$

But this loss is due to scattering and the proportional loss from scattering in the distance dx is of the form $k\sigma dx$, where k is a constant. It follows that

$$(7) \quad \sigma = \frac{3.912}{k v} = \frac{1}{K v},$$

where K is a constant defined by this equation. Hulburt (4) reports that in most situations of comparatively clear air, K is close to 7, and we have used this value in our computations.

In view of the definitions given above, we may conclude that the veiling luminance generated by scattering along the entire line of sight is given by the integral

$$(8) \quad S = \sigma \int_0^D E t^x dx = \frac{1}{Kv} \int_0^D E t^x dx.$$

(Unless the observer's line of sight is parallel to the axis of the beam, the distance differs slightly from D . We neglect such second order quantities throughout.) To evaluate S we must know E as a function of x . In the searchlight beam, the illuminance E varies in accordance with the inverse square law and also depends on the angular distribution of light intensity in the beam.

To make our ideas precise, let us set up a system of rectangular coordinates with the origin at the searchlight, the x -axis along the axis of the (horizontal) beam, the y -axis horizontal, and the z -axis vertical. Then the ray of the searchlight beam from the origin to a point (x, y, z) in the beam makes an angle of $\frac{y}{x}$ radians (or $57.3 \frac{y}{x}$ degrees) with the xz plane and an angle of $\frac{z}{x}$ radians with the xy plane. The angular intensity distribution of the searchlight may be specified by a function $F(\theta, \phi)$, where θ is the angle a given direction makes with the xz plane and ϕ the angle it makes with the xy plane. That is, we suppose that the intensity I of the beam in the direction (θ, ϕ) is equal to $I_0 F(\theta, \phi)$, where I_0 is the intensity of the source in the direction of the axis of the beam. (Thus the curve of Figure 5 is a graph of $F(\theta, 0)$ and $F(0, \phi)$ for a particular searchlight.) It follows that the illuminance of a lamina perpendicular to the beam at the point (x, y, z) is

$$(9) \quad \frac{I_0 t^x}{x^2} F\left(\frac{y}{x}, \frac{z}{x}\right).$$

The expression (9) is valid for an arbitrary point of the beam. Along the line of sight y and z depend on x . Once the relationship is determined, we may substitute in (9) to obtain $E(x)$.

If the observer is in the yz -plane (at the same distance from the target as the searchlight), his coordinates may be written $(0, \ell, h)$. Let the coordinates of the target be (D, L, H) . Then for any point (x, y, z) on the line of sight we have by similar triangles

$$\frac{x}{D} = \frac{y - \ell}{L - \ell} = \frac{z - h}{H - h},$$

whence

$$(10) \quad y = \ell + \frac{L - \ell}{D} x, \quad z = h + \frac{H - h}{D} x.$$

These are the desired relations. Substituting from (10) and (9) gives us

$$(11) \quad E(x) = \frac{I_0 t^x}{x^2} F\left(\frac{\ell}{x} + \frac{L - \ell}{D}, \frac{h}{x} + \frac{H - h}{D}\right) = I_0 t^x u(x),$$

where $u(x)$ is defined by the above relation. We note that $u(x)$ depends only on the locations of the observer and the target and on the angular light distribution in the beam.

Using (11), we may write equation (8) for the veiling luminance in the form

$$(12) \quad S = \frac{I_0}{Kv} \int_0^D u(x) t^{2x} dx = \frac{I_0}{K} f(v),$$

where

$$f(v) = \frac{1}{v} \int_0^D u(x) t^{2x} dx.$$

Since $F(\theta, \phi)$, and hence $u(x)$, is given empirically, numerical or graphical integration must be used in computing $f(v)$.

From (7) and (12) we have

$$(13) \quad C = \frac{(R_T - R_B) t^{2D}}{R_B t^{2D} + D^2 \frac{I_0 f(v)}{IK}}.$$

Note that I is the intensity of the beam in the direction of the target; in terms of our previous notation

$$(14) \quad I = I_0 F\left(\frac{L}{D}, \frac{H}{D}\right).$$

Hence

$$(15) \quad C = \frac{(R_T - R_B) t^{2D}}{R_B t^{2D} + \frac{D^2 f(v)}{KF\left(\frac{L}{D}, \frac{H}{D}\right)}}.$$

Since t depends on v , equation (15) enables us to compute C , given the meteorological range v , the reflectances R_B and R_T , and the target and observer locations. Once C is known, we can obtain the required B_B from Figure 2 as explained earlier. From (4) and (12) we have

$$B_B = \frac{IR_B t^{2D}}{D^2} + \frac{I_0 f(v)}{K} = \frac{I}{D^2} \left[R_B t^{2D} + \frac{D^2 f(v)}{KF\left(\frac{L}{D}, \frac{H}{D}\right)} \right],$$

whence we have for the required candlepower

$$(16) \quad I = \frac{D^2 B_B}{R_B t^{2D} + \frac{D^2 f(v)}{KF\left(\frac{L}{D}, \frac{H}{D}\right)}}$$

(as before B_B must be multiplied by 9 to get the proper units). If desired, the maximum candlepower I_0 can be obtained by dividing by $F\left(\frac{L}{D}, \frac{H}{D}\right)$.

RESTRICTED

The preceding discussion applies to an arbitrary intensity distribution $F(\theta, \phi)$. Since the elliptical distribution considered here is similar in all directions, the treatment may be simplified somewhat in this special case, as follows:

Let the distribution of Figure 5 be denoted by a function $g(\psi)$, where ψ is the directional angle in degrees. The horizontal and vertical 'cross-sections' $F(\theta, 0)$ and $F(0, \phi)$ of the elliptical distribution are the same as the function $g(\psi)$ except for scale. Since $\theta = 4^\circ = \frac{4}{57.3}$ radians corresponds to $\psi = 0.84^\circ$, we have

$$(17) \quad F(\theta, 0) = g\left(\frac{57.3 \cdot 0.84}{4} \theta\right) = g\left(\frac{48.1}{4} \theta\right);$$

similarly

$$F(0, \phi) = g\left(\frac{48.1}{0.5} \phi\right).$$

By the nature of the elliptical distribution, the function $F(\theta, \phi)$ is constant on any elliptical cone of the form $\left(\frac{\theta}{4}\right)^2 + (2\phi)^2 = C^2$. Hence if (θ_0, ϕ_0) is any given direction, we have $F(\theta, \phi) = F(\theta_0, \phi_0)$ for any direction (θ, ϕ) such that

$$(18) \quad \left(\frac{\theta}{4}\right)^2 + (2\phi)^2 = \left(\frac{\theta_0}{4}\right)^2 + (2\phi_0)^2.$$

In particular, (17) is satisfied if $\theta = 4 \sqrt{\left(\frac{\theta_0}{4}\right)^2 + (2\phi_0)^2}$, $\phi = 0$. Hence by (17)

$$(19) \quad F(\theta_0, \phi_0) = F\left(4 \sqrt{\left(\frac{\theta_0}{4}\right)^2 + (2\phi_0)^2}, 0\right) = g\left(48.1 \sqrt{\left(\frac{\theta_0}{4}\right)^2 + (2\phi_0)^2}\right).$$

Equation (19) defines F in terms of the known function g , so that we can proceed with the computations by substituting in (11) and the following equations.

RESULTS

The Original Candlepower Distribution

The results of our calculations with the searchlight candlepower distribution described above are presented in Tables 1 through 12. In all cases, candlepower values are given in millions of candles. In each table, differences in candlepower appear due to variations in the following variables: (a) The meteorological range, v ; (b) the use of the unaided eye, or 6 or 10 power magnification; (c) the use of threshold contrasts, or twice threshold contrast for a safety factor; and (d) the location of the observer's eye with respect to the searchlight. The tables vary between each other with respect to two variables: (a) the position of the target in the searchlight beam and the target's distance from the observer's eye; and (b) the reflectances of target, R_T , and of background, R_B .

Values of h represent vertical displacements, in yards, between the observer's eye and the searchlight. Values of ℓ represent horizontal displacements, in yards. The three sets of values of h and ℓ (2/3, 2/3; 1/3, 2/3; and 1/3, 1) represent cases involving the gunner in the tank bearing the searchlight. Slight vertical and horizontal adjustments might be feasible in the practical situation if one or another set of displacements could be shown to result in markedly reduced candlepower requirements. The set of values, $h = 0$, $\ell = 50$ represents the case involving the gunner in a tank 50 yards distant, in the horizontal dimension, from the tank bearing the searchlight.

RESTRICTED

Tables 1 through 3 represent computations in which $R_B = .00$, $R_T = .13$. Data supplied by Mr. John A. Bartelt of the Engineer Research and Development Laboratories, Fort Belvoir, Virginia, suggest that Russian tanks have reflectances near .13 when dirty. The meaning of $R_B = .00$ is that either the tank is seen silhouetted against the sky or that the background is very far behind the target and hence reflects virtually none of the searchlight illuminance.

Three positions of the target in the searchlight beam are represented in Tables 1 through 3. In Table 1, the target is assumed to occur at the center of the searchlight beam. The military requirement stated by Army Field Forces Board No. 2 was that the enemy tank be detected at 1500 yards when located in the center of the beam. In Tables 2 and 3 the target is assumed to occur at a point 4° from the center of the beam, where the intensity of the beam is 10% of the maximum. The military requirement in this case is that the target be detected at a distance of 1200 yards. Table 2 represents the case in which the target is located in the "near edge" of the beam, that is, on the same side of the center as the observer's eye. Table 3 represents the "far edge," that is, when the target is on the opposite side of center from the observer's eye. In the second case, the observer has to look through more of the searchlight beam than in the first case.

Blank spaces in the tables represent cases in which no amount of candlepower can provide the required conditions for detection. We see from Figures 3 and 4 that if target contrast falls below a given value for each curve, no increase in B_B can make the target detectible. Hence, indefinite increase in searchlight candlepower is of no use.

Examination of the values in Tables 1 through 3 reveals the important roles of v , of magnification, and of contrast criterion. Changes in the position of the observer are of considerably lesser importance.

It is apparent from examining the tables that the candlepower requirements are reduced drastically when we change from unaided eye to 6 power magnification. Considerably less additional improvement is obtained as power is increased from 6 to 10 power. The effect of using the twice-threshold criterion is to increase candlepower requirements by twice or more. The amount of the increase brought about by the change in the criterion is greatest when the apparent contrasts are smallest.

For any of these observing conditions, we may determine the range of atmospheric conditions under which a given candlepower will render the target detectible, from each of the various possible stations of the observer, using each of the two threshold criteria. For example, we may select 10 million candles as a possible center intensity for a tank-mounted searchlight. We note from Table 1 that detections will be possible under all values of v greater than 10,000 yards, regardless of observer station used and regardless of whether we use threshold contrasts or twice-threshold contrasts.

It is instructive to compare with the above the number of conditions under which the military requirement will be met for the target at the edge of the beam. It is to be noted that the candlepowers in Tables 2 and 3 are stated for the edge of the beam. Since the candlepower at the edge of the beam is only 10% of the center value, we have only 1 million candles available at the beam edge when we have 10 million at the center. It is immediately obvious that we cannot meet the military detection requirement at the edge of the beam under many atmospheric conditions. Thus, it appears that the edge requirement is more difficult to meet than the center requirement.

Tables 4-12 differ from the first three only with respect to values of R_T and R_B . Tables 4-6 involve values of $R_T = .13$, $R_B = .06$; Tables 7-9 involve values of $R_T = .10$, $R_B = .06$; Tables 9-12 involve values of $R_T = .08$, $R_B = 1.06$. These conditions represent progressively better concealment of the enemy tank. Values of $R_T = .08$ may be obtained with clean Russian tanks. Values of $R_B = 1.06$ may be obtained with foliage background just behind the enemy tank.

It is apparent that the candlepower requirements increase drastically as the differences between R_B and R_T are reduced. With $R_T = .08$ and $R_B = .06$, at least 50 million candles will be required for reasonably adequate coverage of atmospheric conditions. In all cases, the requirements at the beam edge are more difficult to meet than the requirements at the beam center.

We note that of the three positions for the gunner in the tank bearing the searchlight, $h = 2/3$, $\ell = 2/3$ always leads to the lowest candlepower requirement. The position $h = 1/3$, $\ell = 1$ is next best and the position $h = 1/3$, $\ell = 2/3$ is the worst. As nearly as we can determine from available information, $h = 1/3$, $\ell = 2/3$ is the condition now employed. Displacement of the searchlight away from the gunner's eye by one foot in either direction would improve detectability. The improvement is considerably greater for the one foot displacement in the vertical direction. This is to be expected, since the searchlight beam is so elongated horizontally that a displacement of one foot up or down is roughly equivalent to a displacement of eight feet sideways. The location $h = 0$, $\ell = 50$ consistently yields still lower candlepower values, representing the fact that the gunner in a tank removed 50 yards from the tank bearing the searchlight has a greater chance of detecting the target than a gunner located on the tank. This fact is probably well-known from field tests of tank-mounted searchlights.

The reason for the differences as a function of the observer's location (which disappear for $v = \infty$) is that the observer's line of sight enters the beam much farther out in the better cases than in the others. Due to the inverse square law, the part of the beam closest to the observer contributes a disproportionate amount of veiling luminance. This factor is so important under some conditions as to suggest a careful exploration of all the tactical possibilities.

At this point in our calculations, we investigated the extent to which actual searchlight distributions which might be used by the Army were well represented by our assumed distribution. Mr. John A. Bartelt furnished us with data obtained with two experimental searchlights. The first of these was an 18" searchlight, utilizing a carbon arc source and a spread lens. The horizontal candlepower distribution is shown in Figure 6 as the solid curve. The dashed curve is the horizontal distribution of the searchlight we have used in our calculations. The second was a 12" searchlight, utilizing a high-pressure mercury capillary arc without a spread lens. The horizontal distribution is shown in Figure 7 as the solid curve. The dashed curve is the horizontal distribution of the searchlight we have used. Since the two practical searchlights differ from our assumed searchlight in opposite directions by about the same amount, we conclude that our assumed distribution is a reasonable one for use in the present case.

Both the practical searchlights had broader vertical spreads than our assumed searchlight. Mr. Bartelt provided data on the vertical distribution of the 12" mercury arc searchlight and indicated that the 18" carbon arc searchlight had a similar vertical distribution. The solid curve in Figure 8 presents the data for the mercury light. The dashed curve is the assumed distribution expanded by a factor of two as compared with the distribution used in our calculations. These distributions are reasonably similar, but clearly the assumed 1° distribution is narrower than the distribution obtained in the experimental searchlights.

The geometry of the situation is such that we can readily evaluate the result to be expected if the vertical dimension of the candlepower distribution is doubled. If we double the vertical dimension, this is equivalent to replacing h by $\frac{h}{2}$. Thus, the results given in Tables 1 through 12 for $h = 1/3$, $\ell = 2/3$ are the same as those for $h = 2/3$, $\ell = 2/3$ with the broadened beam. We have already noted that the candlepower requirements are larger for $h = 1/3$, $\ell = 2/3$ than for $h = 2/3$, $\ell = 2/3$. We may interpret this result in the present context as follows: The required candlepower at any point will be greater with the 2° vertical beam than with the 1° vertical beam. In addition, of course, doubling the vertical

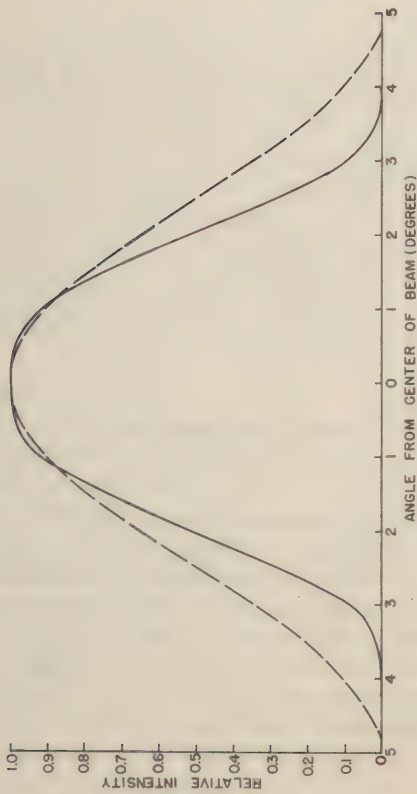


Figure 6: Comparison of Standard Horizontal Candlepower Distribution (dashed curve) and Measured Distribution from 18 in. Carbon Arc Searchlight (solid curve).



Figure 7: Comparison of Standard Horizontal Candlepower Distribution (dashed curve) and Measured Distribution from 12 in. Mercury Arc Searchlight (solid curve).

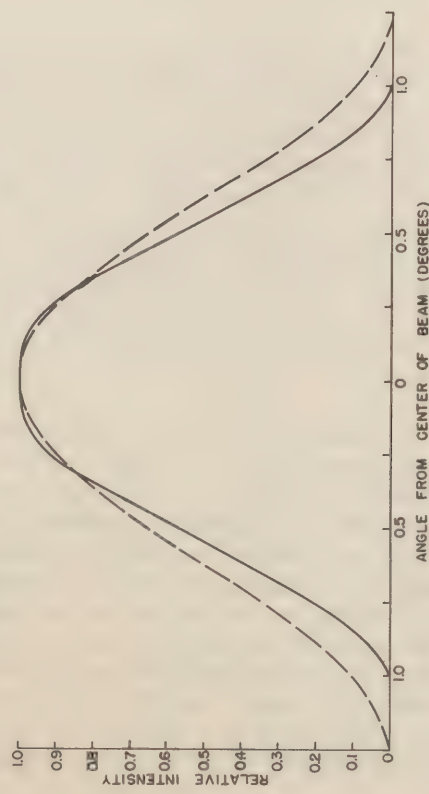


Figure 8: Comparison of Standard Vertical Candlepower Distribution (dashed curve) and Measured Distribution from 12 in. Mercury Arc Searchlight (solid curve).

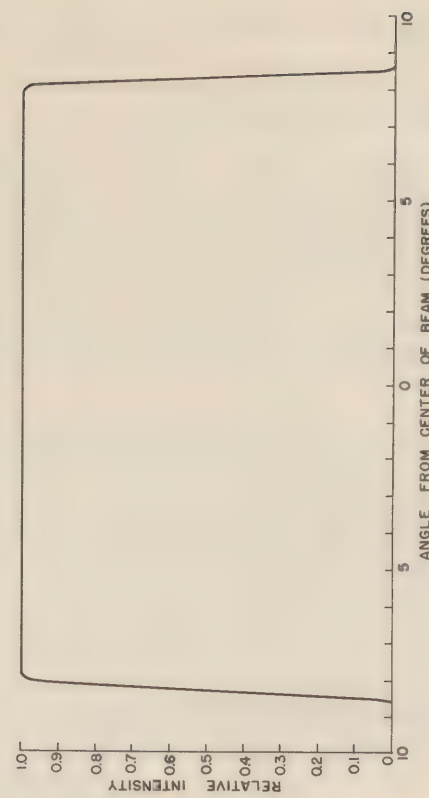


Figure 9: Candlepower Distribution for Theoretical Searchlight.

dimension of the beam will require a total flux in the searchlight beam twice that required previously.

An Alternative Candlepower Distribution

We have noted that the military requirements for targets appearing in the beam edge are more difficult to meet than the requirements for targets appearing in the beam center. This fact led Mr. John A. Bartelt to suggest that we study a candlepower distribution having maximum intensity along a horizontal line, instead of just at a point. The line would subtend an angle of 8° and cross sections of the beam perpendicular to it would have the distribution shown in Figure 5 with a distance of $.5^\circ$ from the center out to the 10% point on each side of center. Along the horizontal axis of the beam, the distribution would be as shown in Figure 9.

We have carried out some computations for this distribution, which we may compare with the original calculations.

To carry out the calculations, we proceed as before through equation (16). In the present case, for $-4^\circ \leq \theta \leq 4^\circ$ the intensity of the beam varies only in the vertical direction, and we have

$$(17a) \quad F(\theta, \phi) = g \left(\frac{48.1}{0.5} \phi \right).$$

If the ends of the distribution beyond $\theta = \pm 4^\circ$ are taken as semicircular, we have for $\theta > 4^\circ$ and $\theta < -4^\circ$

$$(17b) \quad F(\theta, \phi) = g \left(\frac{48.1}{0.5} \sqrt{(\theta \mp 4 \cdot 57.3)^2 + \phi^2} \right),$$

the minus sign holding for $\theta > 4^\circ$ and the plus sign for $\theta < -4^\circ$.

Results of our computations with the second searchlight distribution are presented in Tables 1a through 12a. (These tables are numbered to correspond to the original tables with respect to all variables except the intensity distribution in the searchlight beam.) The first major conclusion obtained from a comparison of the two sets of tables is that the two distributions do not give significantly different results when the target is located in the center of the beam. This result is not entirely unexpected, but the degree of similarity was difficult to anticipate. In the case $h = 2/3$, $\ell = 2/3$, the two beams give essentially the same result since the observer's eye is comparatively near the searchlight, and hence the observer looks at the target through only the center of the searchlight beam. In the case $h = 0$, $\ell = 50$, the two beams give essentially the same result since the line of sight enters the beam so far out that there is little veiling luminance in either case, the variation in required candlepower with v being chiefly due to attenuation.

The second major conclusion is that as much or more edge candlepower is required to see a target appearing in the edge of the beam with the second searchlight distribution as with the first, when the observer is located at $h = 2/3$, $\ell = 2/3$. This result is to be expected, since the additional candlepower near the edges of the second distribution can only increase the veiling luminance, and hence increase the candlepower requirement. The candlepower requirement is not so great, however, as to exceed the candlepower requirement for targets appearing in the center of the beam. Since in this case the edge candlepower is equal to the center candlepower in the searchlight beam, the center candlepower requirement is harder to satisfy than the edge candlepower requirement. It will be recalled that with the original searchlight distribution, the edge requirement was more difficult to satisfy than the center requirement. Thus, flattening the candlepower maximum reverses the comparative difficulty of meeting center and edge candlepower requirements.

In the case $h = 0$, $\ell = 50$, the candlepower requirements on the near side of the beam are virtually the same for the two beams. This result is to be expected, since in each case the observer's eye looks at the target through the edge of the distribution alone, and there is very little veiling luminance. With the second distribution, there is comparatively little difference in the candlepower requirement between the near and far edge cases. This result is at variance to the situation with the first distribution, where the candlepower requirement is somewhat greater when the target is located in the far edge of the beam. The net consequence is that less edge candlepower is required with the second distribution, when the target is in the far edge of the beam.

If we compare the edge with the center requirement where $h = 0$, $\ell = 50$, we obtain the same result as for $h = 2/3$, $\ell = 2/3$. Less candlepower is required to meet the edge requirement than to meet the center requirement.

There is no exact way to infer from our analysis of two searchlight beams the characteristics of a beam which will give us candlepower requirements in the center and at the edge of the beam which are equally difficult to meet. (Such a distribution is to be desired since with it, neither center nor edge candlepower is being wasted.) The first distribution falls to 10% of the center candlepower at $\pm 4^\circ$, and this was shown to lead to more severe candlepower requirements at the edges than in the center. The second distribution is maintained to full center intensity all the way out to $\pm 4^\circ$, and this was shown to lead to more severe candlepower requirements at the center than at the edges. Some distribution between the two extremes would appear to provide balance between beam center and edge requirements. A distribution with 50% of center intensity at $\pm 4^\circ$ may well represent the desirable balance. If such a distribution can be produced physically, calculations can be made to ascertain the extent to which balance has been realized.

NOTE

The present report was prepared in response to a request which originated with Major John L. Fellows, Jr., Army Field Forces Board No. 2, Fort Knox, Kentucky. Major Fellows requested the Vision Committee to provide candlepower specifications for tank-mounted searchlights to be used for direct illumination of ground targets such as enemy tanks during night operations.

Preparation of the report was undertaken by Drs. H. Richard Blackwell and Wilfred M. Kincaid of the Vision Committee Secretariat, University of Michigan, and Dr. S. Q. Duntley, Scripps Institution of Oceanography, University of California. Dr. E. O. Hulburt, Naval Research Laboratory, offered valuable advice at various stages in the preparation of the report.

Discussion:

Dr. Hulburt stated that, in his opinion, it would not be necessary to make empirical measurements with searchlights any more, but that instead one could predict the candlepower required for any given application from the techniques reported by Dr. Blackwell.

Table 1. Intensity in Center of Beam
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .00 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	198	21.2	16.1			
10,000	13.7	3.27	2.43	35.1	7.85	5.56
15,000	7.96	1.95	1.45	19.9	4.28	3.17
20,000	6.07	1.56	1.15	13.3	3.27	2.48
25,000	5.24	1.35	1.00	11.5	2.82	2.13
∞	2.96	.838	.607	5.66	1.64	1.21
$h = 1/3 \quad \ell = 2/3$						
10,000	18.6	4.08	2.89	76.0	11.0	8.14
15,000	9.25	2.16	1.68	23.7	5.31	3.76
20,000	6.93	1.67	1.25	15.9	3.81	2.83
25,000	5.67	1.39	1.05	12.7	3.11	2.36
∞	2.96	.838	.607	5.66	1.64	1.21
$h = 1/3 \quad \ell = 1$						
10,000	18.2	3.97	2.88	70.5	10.7	7.94
15,000	9.14	2.14	1.63	22.4	5.14	3.64
20,000	6.71	1.65	1.24	16.1	3.69	2.80
25,000	5.62	1.41	1.05	12.8	3.16	2.34
∞	2.96	.838	.607	5.66	1.64	1.21
$h = 0 \quad \ell = 50$						
2,000	2873.	498.	372.	19,876	1654.	1282.
5,000	34.1	8.77	6.66	74.6	18.3	13.9
10,000	9.73	2.68	1.99	20.9	5.47	4.06
15,000	6.50	1.80	1.33	13.3	3.57	2.58
20,000	5.37	1.51	1.07	11.0	2.96	2.14
25,000	4.72	1.30	.961	9.61	2.60	1.92
∞	2.96	.838	.607	5.66	1.64	1.21

Table 2. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .00 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	12.4	3.34	2.79	29.2	7.68	6.53
10,000	4.03	1.19	.904	8.63	2.43	1.98
15,000	2.86	.843	.653	5.84	1.72	1.33
20,000	2.47	.714	.554	4.83	1.46	1.13
25,000	2.25	.650	.504	4.49	1.30	1.01
∞	1.54	.445	.338	3.08	.868	.643
$h = 1/3 \quad \ell = 2/3$						
5,000	14.2	3.74	3.11	38.3	9.36	8.00
10,000	4.20	1.18	.965	9.43	2.54	2.12
15,000	2.89	.858	.665	6.21	1.79	1.46
20,000	2.48	.731	.556	5.08	1.49	1.16
25,000	2.25	.649	.502	4.48	1.33	1.03
∞	1.54	.445	.338	3.08	.868	.643
$h = 1/3 \quad \ell = 1$						
5,000	12.9	3.48	2.96	32.5	8.57	7.13
10,000	4.12	1.21	.942	9.00	2.48	2.01
15,000	2.89	.836	.647	5.91	1.74	1.38
20,000	2.44	.706	.548	4.88	1.44	1.12
25,000	2.31	.650	.505	4.49	1.33	1.03
∞	1.54	.445	.338	3.08	.868	.643
$h = 0 \quad \ell = 50$						
2,000	168.	48.5	36.8	335.6	96.7	75.1
5,000	10.1	2.86	2.16	20.3	5.70	4.43
10,000	3.89	1.12	.833	7.76	2.24	1.66
15,000	2.80	.790	.585	5.59	1.57	1.20
20,000	2.42	.680	.505	4.92	1.39	1.03
25,000	2.18	.616	.457	4.36	1.26	.932
∞	1.54	.445	.338	3.08	.868	.643

Table 3. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .00 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	15.7	4.04	3.52	48.6	11.2	9.06
10,000	4.36	1.23	.998	9.76	2.62	2.24
15,000	2.96	.873	.679	6.33	1.75	1.45
20,000	2.48	.733	.567	5.18	1.53	1.19
25,000	2.24	.660	.502	4.58	1.38	1.05
∞	1.54	.445	.338	3.08	.868	.643
$h = 1/3 \quad \ell = 2/3$						
5,000	60.9	8.02	6.52			
10,000	5.61	1.44	1.23	15.1	3.69	3.15
15,000	3.41	.917	.761	8.16	2.15	1.83
20,000	2.67	.754	.612	6.12	1.65	1.37
25,000	2.38	.702	.558	5.33	1.43	1.19
∞	1.54	.445	.338	3.08	.868	.643
$h = 1/3 \quad \ell = 1$						
5,000	37.0	6.88	5.60			
10,000	5.07	1.36	1.13	13.3	3.42	2.92
15,000	3.32	.910	.758	7.46	2.00	1.70
20,000	2.62	.755	.628	5.99	1.61	1.37
25,000	2.32	.685	.544	5.20	1.43	1.17
∞	1.54	.445	.338	3.08	.868	.643
$h = 0 \quad \ell = 50$						
5,000	22.4	5.24	4.39	135.	17.0	13.5
10,000	5.04	1.39	1.16	12.7	3.26	2.84
15,000	3.38	.930	.737	7.58	2.03	1.73
20,000	2.56	.739	.601	5.74	1.58	1.31
25,000	2.34	.674	.535	5.11	1.41	1.15
∞	1.54	.445	.338	3.08	.868	.643

Table 4. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .06 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	$\bar{6}$ power	10 power	Unaided	$\bar{6}$ power	10 power
$h = 2/3 \quad \ell = 2/3$						
10,000	32.5	7.26	5.14	129.	18.7	14.5
15,000	17.0	3.63	3.09	44.6	9.76	7.07
20,000	13.1	3.22	2.38	31.4	7.20	5.33
25,000	11.5	2.75	2.04	25.7	6.15	4.56
∞	5.88	1.55	1.14	12.6	3.23	2.39
$h = 1/3 \quad \ell = 2/3$						
10,000	65.4	9.89	7.31	1079.	40.1	29.8
15,000	21.9	4.90	3.47	87.2	12.9	9.78
20,000	15.4	3.52	2.61	44.4	8.68	6.41
25,000	12.6	2.95	2.23	32.3	7.23	5.12
∞	5.88	1.55	1.14	12.6	3.23	2.39
$h = 1/3 \quad \ell = 1$						
10,000	60.6	9.38	7.14	817.	37.4	27.7
15,000	21.6	4.83	3.50	82.1	12.7	9.61
20,000	15.5	3.47	2.63	43.6	8.49	6.45
25,000	12.4	2.89	2.19	31.	6.92	4.91
∞	5.88	1.55	1.14	12.6	3.23	2.39
$h = 0 \quad \ell = 50$						
2,000	16117.	1470.	1117.			
5,000	72.3	17.8	13.2			
10,000	20.1	5.17	3.83	45.0	11.1	8.20
15,000	13.6	3.41	2.59	29.7	7.12	5.42
20,000	10.9	2.82	2.09	24.0	6.04	4.47
25,000	9.61	2.47	1.83	20.5	5.05	3.91
∞	5.88	1.55	1.14	12.6	3.23	2.39

Table 5. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	28.1	7.20	6.28	82.6	19.4	15.7
10,000	8.43	2.33	1.90	18.8	5.07	4.32
15,000	5.74	1.65	1.31	12.8	3.44	2.86
20,000	4.76	1.40	1.09	10.4	2.85	2.38
25,000	4.44	1.27	1.01	9.67	2.61	2.16
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 1/3 \quad \ell = 2/3$						
5,000	36.0	8.90	7.52	154.	26.1	22.2
10,000	8.80	2.42	1.97	21.6	5.56	4.84
15,000	5.99	1.69	1.38	13.7	3.60	3.14
20,000	4.86	1.40	1.11	9.92	2.93	2.49
25,000	4.35	1.31	1.02	9.75	2.69	2.18
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 1/3 \quad \ell = 1$						
5,000	30.2	7.75	6.60	105.	21.8	17.7
10,000	8.64	2.38	1.95	20.2	5.32	4.63
15,000	5.71	1.65	1.34	13.4	3.52	2.92
20,000	4.76	1.41	1.12	10.9	2.94	2.43
25,000	4.22	1.25	.991	9.45	2.60	2.11
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 0 \quad \ell = 50$						
2,000	324.	95.5	74.2			
5,000	18.8	5.53	4.30	39.3	11.6	9.20
10,000	7.38	2.17	1.68	15.7	4.52	3.59
15,000	5.32	1.57	1.22	11.3	3.28	2.60
20,000	4.47	1.32	1.02	9.76	2.82	2.24
25,000	4.09	1.21	.936	8.93	2.58	2.05
∞	2.85	.842	.652	5.94	1.76	1.40

Table 6. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	$\bar{6}$ power	$\bar{10}$ power	Unaided	$\bar{6}$ power	$\bar{10}$ power
$h = 2/3$				$\ell = 2/3$		
5,000	44.1	10.1	8.27	284	33.4	26.5
10,000	9.54	2.55	2.13	23.2	6.12	5.20
15,000	6.13	1.69	1.38	13.7	3.77	3.14
20,000	4.99	1.41	1.14	11.4	3.00	2.55
25,000	4.52	1.30	1.03	10.1	2.77	2.31
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 1/3$				$\ell = 2/3$		
10,000	13.5	3.32	2.89	56.3	10.0	8.14
15,000	7.58	2.04	1.74	21.4	5.13	4.36
20,000	5.76	1.59	1.32	14.8	3.80	3.31
25,000	5.15	1.38	1.15	12.1	3.17	2.76
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 1/3$				$\ell = 1$		
5,000	576.	28.9	19.5			
10,000	12.1	3.10	2.70	42.8	8.93	7.10
15,000	7.21	1.89	1.69	18.5	4.76	4.14
20,000	5.78	1.53	1.27	13.9	3.57	3.11
25,000	5.06	1.36	1.13	11.6	3.12	2.60
∞	2.85	.842	.652	5.94	1.76	1.40
$h = 0$				$\ell = 50$		
5,000	112.	15.1	12.0			
10,000	11.6	2.97	2.59	37.4	8.20	6.78
15,000	6.95	1.91	1.59	17.8	4.68	3.98
20,000	5.60	1.54	1.25	13.4	3.53	3.00
25,000	4.84	1.30	1.09	11.3	2.98	2.60
∞	2.85	.842	.652	5.94	1.76	1.40

Table 7. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .06 \quad R_T = .10$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
			$h = 2/3$	$\ell = 2/3$		
10 000	90.7	15.2	11.5	760.	53.9	40.9
15,000	36.3	8.11	5.88	132.	20.8	15.4
20,000	25.6	5.99	4.54	72.	14.7	10.9
25,000	21.9	5.12	3.97	56.2	12.5	8.89
∞	11.	2.81	2.08	24.5	6.02	4.46
			$h = 1/3$	$\ell = 2/3$		
10,000	420.	27.8	21.5			
15,000	61.8	10.2	7.77	513.	36.3	27.6
20,000	34.4	6.75	5.21	150.	20.2	15.4
25,000	26.2	5.87	4.26	91.2	15.1	11.5
∞	11.	2.81	2.08	24.5	6.02	4.46
			$h = 1/3$	$\ell = 1$		
10,000	348.	26.4	20.1			
15,000	60.8	10.3	7.66	461.	35.8	27.2
20,000	33.9	7.24	5.24	145.	19.9	15.2
25,000	26.3	5.90	4.27	89.2	15.2	11.5
∞	11.	2.81	2.08	24.5	6.02	4.46
			$h = 0$	$\ell = 50$		
5,000	145.	37.9	25.6	371.	82.9	58.8
10,000	38.3	9.38	6.96	86.3	20.6	15.6
15,000	24.7	6.09	4.78	55.2	13.6	10.1
20,000	20.	5.01	3.89	46.7	11.2	8.33
25,000	18.3	4.61	3.48	41.	9.83	7.29
∞	11.	2.81	2.08	24.5	6.02	4.46

Table 8. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .10$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
			$h = 2/3$	$\ell = 2/3$		
5,000	64.2	15.4	13.4	294.	46.4	38.7
10,000	16.0	4.42	3.60	39.3	10.4	8.82
15,000	11.2	3.08	2.50	26.2	6.88	5.86
20,000	9.26	2.55	2.08	20.8	5.58	4.74
25,000	8.05	2.28	1.84	18.8	4.96	4.13
∞	5.18	1.53	1.21	11.6	3.20	2.59
			$h = 1/3$	$\ell = 2/3$		
5,000	104.	20.6	16.8	2022.	99.4	67.0
10,000	18.4	4.84	4.12	50.7	12.2	10.6
15,000	11.4	3.14	2.56	28.0	7.37	6.27
20,000	9.69	2.61	2.12	22.2	5.84	4.96
25,000	8.31	2.28	1.87	19.0	5.00	4.26
∞	5.18	1.53	1.21	11.6	3.20	2.59
			$h = 1/3$	$\ell = 1$		
5,000	81.1	18.1	14.8	601.4	61.6	50.1
10,000	16.5	4.54	3.77	43.3	11.1	9.46
15,000	11.4	3.06	2.54	26.7	7.02	6.11
20,000	9.30	2.55	2.13	20.8	5.59	4.87
25,000	8.24	2.32	1.85	18.8	5.07	4.22
∞	5.18	1.53	1.21	11.6	3.20	2.59
			$h = 0$	$\ell = 50$		
2,000	590.	170.	155.	1318.	364.	295.
5,000	34.1	9.84	7.45	74.2	20.9	17.0
10,000	13.3	3.93	3.05	29.2	8.23	6.69
15,000	9.89	2.92	2.26	21.7	6.12	4.96
20,000	8.14	2.40	1.90	18.2	5.02	4.07
25,000	7.44	2.19	1.74	16.6	4.59	3.72
∞	5.18	1.53	1.21	11.6	3.20	2.59

Table 9. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .10$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	175.	24.8	20.6			
10,000	19.4	4.97	4.23	59.8	13.4	10.9
15,000	12.	3.28	2.74	30.7	7.89	6.71
20,000	9.49	2.61	2.13	22.8	5.99	5.09
25,000	8.78	2.37	1.92	20.1	5.41	4.50
∞	5.18	1.53	1.21	11.6	3.20	2.59
$h = 1/3 \quad \ell = 2/3$						
10,000	40.7	8.14	6.61	793.	39.	26.9
15,000	16.9	4.26	3.71	69.1	12.8	10.4
20,000	12.	3.55	2.69	38.	8.89	7.08
25,000	10.	2.64	2.24	27.	6.62	5.77
∞	5.18	1.53	1.21	11.6	3.20	2.59
$h = 1/3 \quad \ell = 1$						
10,000	33.9	7.42	6.04	339.	28.2	20.9
15,000	15.4	3.95	3.37	52.1	11.1	9.06
20,000	11.3	3.03	2.58	32.5	7.64	6.49
25,000	9.88	2.60	2.21	25.4	6.37	5.54
∞	5.18	1.53	1.21	11.6	3.20	2.59
$h = 0 \quad \ell = 50$						
10,000	29.7	6.83	5.56	196.	22.6	17.5
15,000	15.1	3.89	3.31	50.1	10.7	8.72
20,000	11.4	3.01	2.62	31.5	7.72	6.59
25,000	9.66	2.60	2.21	25.4	6.38	5.43
∞	5.18	1.53	1.21	11.6	3.20	2.59

Table 10. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .06 \quad R_T = .08$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
10,000	873.	56.4	43.7			
15,000	134.	21.8	16.2	1476.	83.0	61.6
20,000	77.0	17.3	11.4	386.	44.4	34.4
25,000	56.2	12.6	8.89	223.	33.1	25.1
∞	24.5	6.02	4.46	56.1	13.1	9.97
$h = 1/3 \quad \ell = 2/3$						
15,000	589.	38.0	29.5			
20,000	150.	20.2	15.4	5583.	97.2	68.7
25,000	93.0	15.1	11.5	757.	53.6	41.6
∞	24.5	6.02	4.46	56.1	13.1	9.97
$h = 1/3 \quad \ell = 1$						
15,000	472.	35.8	27.8			
20,000	145.	19.9	15.1	4361.	91.0	66.0
25,000	89.2	15.2	11.2	692.	52.5	39.9
∞	24.5	6.02	4.46	56.1	13.1	9.97
$h = 0 \quad \ell = 50$						
5,000	371.	83.0	58.8	1477.	214.	166.
10,000	87.5	20.6	15.6	225.	50.5	35.7
15,000	55.2	13.6	10.3	136.	31.1	23.1
20,000	45.7	11.2	8.33	110.	25.1	18.6
25,000	39.1	9.39	6.98	93.9	22.0	16.3
∞	24.5	6.02	4.46	56.1	13.1	9.97

Table 11. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .08$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
			$h = 2/3$	$\ell = 2/3$		
5,000	281.	46.5	38.7			
10,000	39.3	10.4	8.82	128.	28.6	22.7
15,000	26.2	6.88	5.86	68.8	17.7	15.1
20,000	20.8	5.58	4.74	52.	13.7	11.7
25,000	18.4	4.96	4.13	45.2	11.9	10.1
∞	11.6	3.11	2.66	26.6	7.0	5.94
			$h = 1/3$	$\ell = 2/3$		
5,000	2025.	102.	68.6			
10,000	50.7	12.2	10.6	220.	36.7	30.5
15,000	28.	7.19	6.27	84.6	19.3	15.8
20,000	22.2	5.84	4.97	59.7	14.7	12.8
25,000	19.	5.23	4.46	51.2	12.8	10.9
∞	11.6	3.11	2.66	26.6	7.0	5.94
			$h = 1/3$	$\ell = 1$		
5,000	616.	62.9	48.9			
10,000	42.3	11.1	9.46	154.	32.1	25.5
15,000	26.7	7.17	6.11	76.9	18.1	15.
20,000	21.8	6.42	4.87	55.9	14.1	12.2
25,000	18.8	5.07	4.22	48.4	12.2	10.4
∞	11.6	3.11	2.66	26.6	7.0	5.94
			$h = 0$	$\ell = 50$		
2,000	1318.	364.	295.			
5,000	76.3	21.	17.1	179.	47.0	39.1
10,000	29.2	8.02	6.69	66.9	17.6	15.3
15,000	21.7	5.95	4.96	49.6	13.0	11.3
20,000	18.6	5.12	4.27	42.7	11.2	9.76
25,000	16.6	4.46	3.81	38.1	10.0	8.53
∞	11.6	3.11	2.66	26.6	7.0	5.94

Table 12. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .08$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
10,000	59.8	13.4	10.9	386.	45.4	35.2
15,000	34.4	7.89	6.71	111.	24.4	19.4
20,000	23.9	6.26	5.34	70.3	16.5	13.8
25,000	20.1	5.29	4.50	54.1	13.3	11.6
∞	11.6	3.11	2.66	26.6	7.00	5.94
$h = 1/3 \quad \ell = 2/3$						
10,000	813.6	39.0	26.9			
15,000	74.0	12.8	10.7			
20,000	39.7	8.89	7.25	309.	30.9	24.0
25,000	27.0	6.78	5.77	113.	20.0	16.7
∞	11.6	3.11	2.66	26.6	7.00	5.94
$h = 1/3 \quad \ell = 1$						
10,000	332.	27.6	20.9			
15,000	54.6	11.4	9.06	721.	48.6	35.3
20,000	34.1	7.97	6.77	175.	25.2	20.5
25,000	26.0	6.67	5.68	98.8	19.7	15.6
∞	11.6	3.11	2.66	26.6	7.00	5.94
$h = 0 \quad \ell = 50$						
10,000	188.	22.6	17.9			
15,000	50.1	10.7	8.72	479.	40.8	30.2
20,000	31.5	7.72	6.58	153.	23.2	19.7
25,000	24.8	6.38	5.43	90.3	18.8	14.6
∞	11.6	3.11	2.66	26.6	7.00	5.94

~~RESTRICTED~~

Table 1a. Intensity in Center of Beam
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .00 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 Power
$h = 2/3 \quad \ell = 2/3$						
5,000	170.	20.	15.5			
10,000	13.9	3.25	2.46	36.5	7.98	5.66
20,000	6.14	1.58	1.17	13.4	3.30	2.49
$h = 0 \quad \ell = 50$						
5,000	37.4	9.19	6.99	85.9	20.1	15.3
10,000	10.2	2.67	1.98	21.7	5.58	4.14
20,000	5.51	1.49	1.10	11.	3.03	2.19

Table 2a. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .00 \quad R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	16.9	4.35	3.62	58.9	12.3	9.98
10,000	4.75	1.31	1.06	10.2	2.73	2.28
20,000	2.46	.726	.563	5.25	1.51	1.23
$h = 0 \quad \ell = 50$						
5,000	10.2	3.	2.28	20.3	5.99	4.65
10,000	3.96	1.17	.888	7.90	2.28	1.77
20,000	2.48	.716	.532	4.96	1.46	1.11

~~RESTRICTED~~

Table 3a. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .00$$

$$R_T = .13$$

v (yards).	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
5,000	16.9	4.35	3.62	58.9	12.3	9.98
10,000	4.75	1.31	1.06	10.2	2.73	2.28
20,000	2.46	.726	.563	5.25	1.51	1.23
$h = 0 \quad \ell = 50$						
5,000	11.5	3.16	2.57	25.7	6.90	5.76
10,000	3.92	1.16	.900	8.20	2.42	1.88
20,000	2.46	.710	.538	4.91	1.45	1.10

Table 4a. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .06$$

$$R_T = .13$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
$h = 2/3 \quad \ell = 2/3$						
10,000	33.6	7.36	5.22	131.	19.8	14.7
20,000	13.5	3.15	2.40	31.6	7.25	5.37
$h = 0 \quad \ell = 50$						
5,000	84.9	17.3	14.1	209.	46.7	33.
10,000	20.9	5.13	3.97	46.8	11.5	8.47
20,000	11.1	2.79	2.12	24.3	5.95	4.53

~~RESTRICTED~~

Table 5a. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .13$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
5,000	52.8	11.5	9.17	697.	48.1	34.1
10,000	9.48	2.56	2.23	25.	6.42	5.47
20,000	5.21	1.47	1.19	12.	3.21	2.67
			$h = 0$	$\ell = 50$		
5,000	20.	5.78	4.28	42.8	11.8	9.83
10,000	7.49	2.21	1.71	16.	4.53	3.68
20,000	4.69	1.38	1.05	9.57	2.82	2.29

Table 6a. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .13$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 Power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
5,000	52.8	11.5	9.17	697.	48.1	34.1
10,000	9.48	2.56	2.23	25.	6.42	5.47
20,000	5.21	1.47	1.19	12.	3.21	2.67
			$h = 0$	$\ell = 50$		
5,000	24.7	6.66	5.66	63.5	16.3	14.2
10,000	8.04	2.26	1.88	18.8	4.97	4.12
20,000	4.81	1.42	1.10	10.5	2.84	2.35

~~RESTRICTED~~

Table 7a. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_E = .06 \quad R_T = .10$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
10,000	95.2	15.7	11.7	845.	55.9	43.3
20,000	26.3	6.17	4.58	74.2	14.8	11.0
			$h = 0$	$\ell = 50$		
5,000	173.	39.7	28.8	617.	102.	75.7
10,000	39.7	9.77	7.40	95.4	21.9	16.2
20,000	20.7	5.08	3.85	46.5	11.3	8.43

Table 8a. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .10$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
5,000	333.	31.8	25.3			
10,000	20.8	5.34	4.54	68.8	15.1	11.9
20,000	10.2	2.67	2.28	24.4	6.41	5.46
			$h = 0$	$\ell = 50$		
5,000	36.5	10.3	8.15	83.8	22.5	19.1
10,000	14.3	4.02	3.28	32.0	8.63	7.17
20,000	8.52	2.52	2.00	19.5	5.26	4.36

Table 9a. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .10$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
5,000	333.	31.8	25.3			
10,000	20.8	5.34	4.54	68.8	15.1	11.9
20,000	10.2	2.67	2.28	24.4	6.41	5.46
			$h = 0$	$\ell = 50$		
5,000	52.9	13.6	11.6	175.	38.4	30.4
10,000	16.0	4.32	3.60	38.6	10.1	8.62
20,000	8.76	2.48	1.96	20.0	5.40	4.49

Table 10a. Intensity at Beam Center
(millions of candles)

Target in Beam Center at 1500 yards

$$R_B = .06 \quad R_T = .08$$

<u>v (yards)</u>	<u>Thresholds</u>			<u>2x Thresholds</u>		
	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>	<u>Unaided</u>	<u>6 power</u>	<u>10 power</u>
			$h = 2/3$	$\ell = 2/3$		
10,000	826.	55.9	42.4			
20,000	72.5	14.8	11.0	355.	43.7	33.2
			$h = 0$	$\ell = 50$		
5,000	617.	102.	75.7	5481.	362.	281.
10,000	97.7	22.9	16.9	295.	54.9	41.6
20,000	45.3	11.3	8.43	116.	26.0	18.9

Table 11a. Intensity at Edge of Beam
(millions of candles)

Target in Near Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .08$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
			$h = 2/3$	$l = 2/3$		
10,000	68.8	15.0	12.2	737.	57.2	42.4
20,000	30.7	6.27	5.46	75.4	17.2	14.0
			$h = 0$	$l = 50$		
5,000	83.8	23.0	19.6	219.	56.5	49.2
10,000	31.3	8.43	7.01	74.9	19.7	16.8
20,000	19.5	5.26	4.28	45.7	11.8	10.3

Table 12a. Intensity at Edge of Beam
(millions of candles)

Target in Far Edge of Beam at 1200 yards

$$R_B = .06 \quad R_T = .08$$

v (yards)	Thresholds			2x Thresholds		
	Unaided	6 power	10 power	Unaided	6 power	10 power
			$h = 2/3$	$l = 2/3$		
10,000	68.8	15.0	12.2	737.	57.2	42.4
20,000	30.7	6.27	5.46	75.4	17.2	14.0
			$h = 0$	$l = 50$		
5,000	175.	37.4	30.4	1875.	146.	108.
10,000	37.6	9.90	8.42	108.	26.1	21.2
20,000	20.1	5.52	4.49	49.1	13.0	11.0

THE INFLUENCE OF YELLOW-TINTED GLASSES UPON VISIBILITY AT LOW LUMINANCE*

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In recent months, two yellow-tinted glasses have been extensively advertised for use in night driving. Both of these products are alleged to reduce the glare effect of opposing headlights. One is alleged to do so without loss in the visibility of objects of interest along the highway. The other is alleged actually to increase visibility of objects of interest as well as to reduce glare.

It is well known that glare has a deleterious effect upon visual performance. There appears to be a direct loss in visual performance which is probably the result of stray light scattered from the glare source which reduces the contrast of visual targets of interest. There is also a possible indirect loss in visual performance due to the unpleasant effects of glare. It is apparent that reduction of glare will improve visual performance, provided all other conditions are unchanged. Glare can presumably be reduced by any absorbing filter, tinted or neutral. Whether one or another filter is most effective in reducing the direct and indirect effects of glare does not appear to be established at the present time.

There is sufficient experimental evidence to indicate that the use of a neutral filter for the purpose of reducing glare would have a deleterious effect upon any kind of visual performance required at the comparatively low luminances encountered in night driving. Studies of the effects of tinted filters at low luminance have apparently not been made. There does not seem to be any reason to expect tinted filters to have a lesser deleterious effect upon visual performance at low luminance than neutral filters of equal luminous transmission. However, there seems to be just enough uncertainty about this point to justify an experimental study.

The present study was designed, accordingly, to test the effects of two yellow-tinted glasses upon visual performance at low luminance. Tests have been made in the laboratory with and without glare intended to simulate the case of opposing headlights. These tests confirm our expectation that the yellow-tinted glasses reduce visual performance whether or not glare is present.

The promotion for one of the two glasses includes the claim that glare is reduced by the glasses without a decrease in "visual acuity." It will be appropriate to begin by demonstrating that visual acuity, in the usual sense of the term, is not the primary capacity involved in night driving.

Reference is made to Figure 1. The experimental data in the

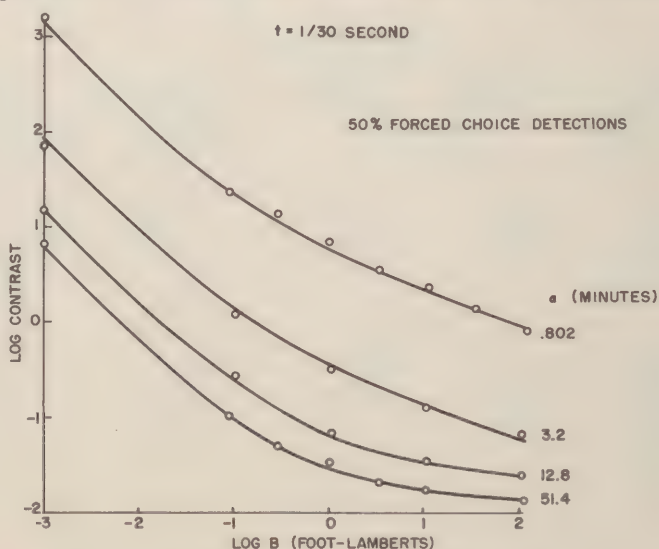


Figure 1. Threshold Data of Blackwell and McCready.

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figure have been reported by Blackwell and McCready elsewhere in these Minutes. The data exhibit the relation between threshold target contrast and background luminance, B , for circular targets of each of four angular sizes. Angular size is defined by α , the angular subtense of the diameter of the target in minutes of arc. The quantity, t , refers to the time of target exposure.

The luminances involved in night driving are usually less than .1 foot-Lamberts. Target contrasts are usually in the range from .1 to .3. The angular size of target usually involved is therefore about 40 to 50 minutes of arc. Clearly, visual acuity in the visual sense is not involved when the target is as large as this at threshold. In the night driving case, we usually need to detect the presence of the pedestrian, not to resolve individual hairs on his head.

It is important to establish that fine resolution is not usually involved in night driving. Judging from the pertinent literature, there is no simple effect of tinted filters upon visual resolution. It is not our intention to become involved in this question, since it does not appear relevant to the usual night driving situation. On the basis of these considerations, our tests involve visual detection of comparatively large, low-contrast targets.

Procedures

The basic experimental procedures for the present study are identical with those described in detail in these Minutes in the report of the Blackwell and McCready data. It will be necessary, accordingly, to describe only the procedures which differ between the experiments.

In the present study, the variable introduced within each experimental session was not target contrast, but was target size. The use of target size as the inter-session variable is not feasible under most experimental conditions, since probability of detection does not bear a simple relation to target size. At low luminance, however, the use of target size is reasonably satisfactory. Numerous experiments have verified that it is approximately valid to predict target detection distances from data on target size obtained at one distance. The use of target size as the variable has the advantage that we can evaluate the effect of tinted glasses upon target detection distances with a minimum of experimentation.

The basic procedure involved comparing experimental sessions in which no glasses were used with experimental sessions in which tinted glasses were used. One hundred presentations were made with a given target size, the first 50 with (or without) glasses, the second 50 under the opposite conditions. Subsequently, 100 more presentations were made with the same target size. The second time, the order of experimental conditions was reversed. Eventually, the procedure was followed for four other target sizes. The order of "glasses" versus "no glasses" was random for different target sizes. Consequently, there is no reason to expect any bias due to the temporal order of the experimental conditions.

The observers were required to work for 100 target presentations at a session, occupying approximately 40 minutes. The same observers were required to return later during the same half-day for two more sessions of 100 presentations each.

The target for all the experiments was a bright rectangle, whose height was six times its width. This target was selected to represent the approximate dimensions of a pedestrian. The target exposure time was $1/30$ second to represent the rapidity with which detection must occur in a rapidly moving vehicle. The color temperature of target and background luminance was 2360° K.

Experiments without glare were conducted with the target presented in the center of the large uniformly bright screen described in the Blackwell and McCready report. On the experiments with glare, a radically different arrangement was employed. The large screen

was covered with a black mask except for a central elliptical area intended to simulate the area of the highway illuminated by automobile headlights. A pair of glare sources was mounted to the left of the target, as viewed by the observers. The separation between the glare sources, and the distance from the glare sources to the target could be varied to simulate the relations to be expected at various highway distances. If the pedestrian target is assumed to have a height of 5 feet, the distance between "headlights" was 4.7 feet, and the distance from the midpoint between the "headlights" and the target was 14.2 feet. The highway distances simulated by the target arrays were: 229, 286, 355, 448, and 556 feet.

The two yellow-tinted glasses will be designated "Filter 1" and "Filter 2." Spectrophotometric curves for samples of these glasses are presented in Figures 2 and 3. Filter 1 is a pale yellow glass, whereas Filter 2 is a deep amber glass. Tinted lenses of both glasses, fitted in comfortable frames, were purchased from a local optician.

Six observers were used in some tests, whereas four of them were used in other tests. Observers were all highly skilled and were known to have at least 20/20 visual acuity.

The forced-choice psychophysical procedure described in detail in the Blackwell and McCready report was used. The data consisted of proportions of correct forced-choice detections and the angular size of the target. Corrections were made for chance successes and the data were evaluated by the probit analysis in terms of normal ogives.

Results

The first experiment involved Filter 1 with glare. The background luminance in the vicinity of the target was .241 foot-Lamberts. The target contrast was .104. Results of the probit analyses are presented in Table 1. The values of M represent the angular subtense of the height of the target, in minutes of arc, corresponding to 50% forced-choice detections, after correction for chance. The values of σ_M represent standard errors of M computed from the probit analysis. Values of σ represent the steepness of the normal ogives, and values of σ_σ represent standard errors of these values. The values of χ^2 indicate the goodness of fit of the experimental proportions to the normal ogive fitted by the probit analysis. The values of $P(\chi^2)$ represent the probability that so poor a fit, or a poorer one, could have occurred by chance. A total of 6,000 target observations was made in this experiment.

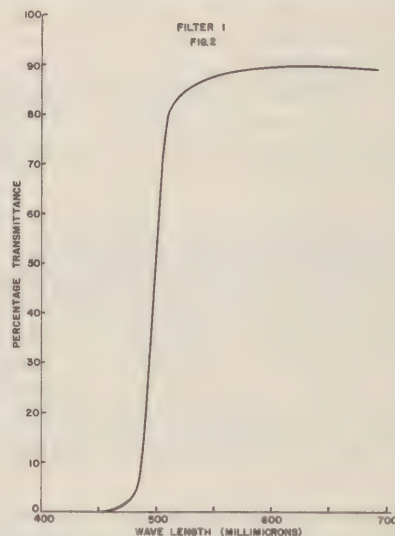


Figure 2. Spectrophotometric Data on Filter 1.

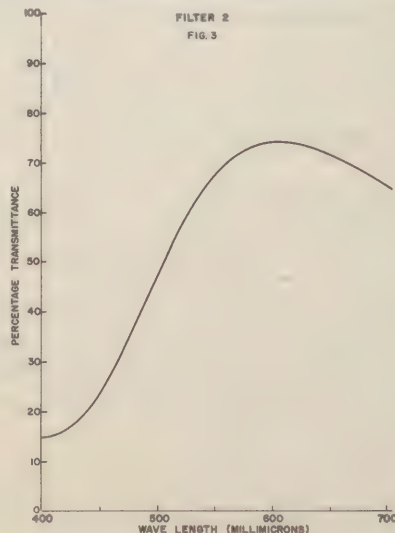


Figure 3. Spectrophotometric Data on Filter 2.

The results of the experiment are analyzed for significance in Table 1a. The column designated "proportional loss" represents the threshold angular size obtained without glasses divided by the threshold obtained with glasses. This is the proportional loss in target detection distance. The next column contains evaluations of the significance of the loss in target detection distance. The significance was tested by the critical ratio technique. The difference between the values of M obtained with and without glasses was evaluated in terms of the standard error of the difference, computed from the standard errors of the two means, assumed to be without correlation. The resulting critical ratio appears in the table. The null hypothesis we are testing here is that either there was no difference, or that the tinted glasses improved target detection distance. Hence, we evaluate the critical ratio using the one-tailed assumption. We note from Table 1a that three observers show unmistakably significant losses. The other three observers show losses, but without significance.

It will be useful to convert the data into average target detection distances. This may be accomplished by using the average M values in Table 1. The detection distance, χ , is given in feet from the relation:

$$\frac{5}{\chi} \times 3436 = M$$

(This equation represents the conversion from radians to minutes of arc. The 5 refers to the assumed height of the pedestrian, in feet.) We obtain values of 311 feet for no glasses and 291 feet for glasses. This loss in detection distance would seem to have practical significance even though it represents quite a small percentage loss.

Table 1: Filter 1 With Glare

No Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	61.8	1.63	16.6	1.87	5.69	.13
LP	50.2	1.15	10.2	1.21	1.15	.78
HF	60.8	1.36	12.2	1.46	8.90	.031
VL	56.9	1.27	10.8	1.39	.0913	.99
NS	41.5	1.20	12.1	1.35	14.6	.002
AK	61.2	1.42	12.7	1.49	5.74	.13
Average	55.4					
Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	68.5	1.46	12.2	1.54	1.66	.65
LP	51.4	1.10	8.98	1.15	1.49	.68
HF	65.7	1.42	11.8	1.49	7.87	.048
VL	57.2	1.29	11.2	1.45	6.25	.10
NS	45.6	1.16	11.3	1.25	1.90	.59
AK	63.6	1.46	13.0	1.55	1.22	.75
Average	58.7					

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Table 1a: Filter 1 With Glare

<u>Observer</u>	<u>Proportional Loss</u>	<u>Critical Ratio of Loss</u>	<u>Probability of Chance Occurrence</u>
AM	.903	2.97	.002
LP	.975	0.81	.21
HF	.924	2.50	.006
VL	.994	0.19	.43
NS	.910	2.44	.007
AK	.959	1.28	.10
Average	.943		

The second experiment was identical to the first except that the Filter 2 glasses were used. The basic data are presented in Table 2 and the analysis of the significance of the detection loss is presented in Table 2a. This experiment involves a total of 2600 target observations. The losses in detection distance are undeniably significant for each of the four observers. The average target detection distances are 349 feet without glasses and 280 feet with glasses. The loss due to the Filter 2 glasses seems to have undeniable practical significance.

Table 2: Filter 2 With Glare

<u>No Glasses</u>						
<u>Observer</u>	<u>M</u>	<u>σ_M</u>	<u>σ</u>	<u>σ_σ</u>	<u>χ^2</u>	<u>$P(\chi^2)$</u>
AM	50.4	2.50	17.8	2.74	.476	.79
LP	45.2	1.10	7.79	1.17	1.65	.45
HF	50.5	1.24	6.83	1.29	7.52	.02
VL	51.1	1.53	15.6	2.20	.206	.90
Average	49.3					

<u>Glasses</u>						
<u>Observer</u>	<u>M</u>	<u>σ_M</u>	<u>σ</u>	<u>σ_σ</u>	<u>χ^2</u>	<u>$P(\chi^2)$</u>
AM	65.8	1.69	14.2	2.00	2.34	.13
LP	56.0	1.17	9.17	1.22	5.92	.015
HF	61.9	1.31	9.54	1.42	.339	.57
VL	62.8	1.58	14.0	2.37	2.53	.11
Average	61.6					

Table 2a: Filter 2 With Glare

<u>Observer</u>	<u>Proportional Loss</u>	<u>Critical Ratio of Loss</u>	<u>Probability of Chance Occurrence</u>
AM	.767	4.37	< .001
LP	.808	6.50	< .001
HF	.815	6.15	< .001
VL	.814	5.17	< .001
Average	.801		

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The third experiment involved the Filter 1 glasses without glare. The background luminance was set at .0444 foot-Lamberts and the target contrast was .271. The data are presented in Tables 3 and 3a. A total of 5800 target observations was made. It is apparent from Table 3a that significant losses occurred for each of four observers. One of the two others showed a loss, whereas the other showed absolutely no difference. The average target detection distances are 342 feet for no glasses and 314 feet for glasses.

Table 3: Filter 1 Without Glare

No Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	58.6	1.73	19.0	2.12	11.2	.024
LP	46.1	1.20	11.9	1.31	7.60	.06
HF	43.4	1.53	14.3	1.76	13.6	.004
VL	50.1	1.40	14.9	1.68	3.09	.37
NS	42.7	1.09	10.3	1.27	1.56	.45
AK	61.3	1.82	20.3	2.34	9.82	.020
Average	50.4					

Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	58.6	1.96	22.9	2.70	1.44	.71
LP	51.9	1.46	15.8	1.82	3.30	.35
HF	48.6	1.61	16.8	1.89	4.12	.25
VL	56.2	1.60	16.9	2.17	7.82	.050
NS	48.2	1.15	10.4	1.49	.592	.74
AK	64.8	2.33	27.9	3.81	6.46	.09
Average	54.7					

Table 3a: Filter 1 Without Glare

Observer	Proportional Loss	Critical Ratio of Loss	Probability of Chance Occurrence
AM	1.000	0.00	.50
LP	.886	3.17	<.001
HF	.890	2.39	.008
VL	.890	2.91	.002
NS	.890	3.34	<.001
AK	.946	1.19	.120
Average	.917		

The fourth experiment involved the Filter 2 glasses without glare. The background luminance was .0456 foot-Lamberts and the target contrast was .339. A total of 3900 target presentations was made. The results are presented in Tables 4 and 4a. We note that all observers show highly significant losses. The average target detection distances are 409 feet without glasses and 295 feet with glasses.

Taking the results of the four experiments together, we have 18,300 observations in all. There are 20 instances in which comparisons have been made between no glasses and glasses. In 19 of these, there was a loss, whereas in the other, there was no difference.

Fifteen of these 19 instances were shown to be individually significant. Losses for Filter 1 range from 11% to less than 1%. Losses for Filter 2 range from 32% to 18%. These results clearly indicate that the yellow-tinted glasses tested produce the expected loss in target detection distance, whether or not glare is present.

Table 4: Filter 2 Without Glare

No Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	51.5	1.96	22.1	2.58	8.29	.040
LP	35.2	1.42	13.5	1.66	7.37	.06
HF	37.5	1.24	8.78	1.37	.107	.95
VL	43.9	1.31	14.0	1.53	14.1	.003
Average	42.0					

Glasses						
Observer	M	σ_M	σ	σ_σ	χ^2	$P(\chi^2)$
AM	66.7	2.18	25.0	3.29	2.45	.49
LP	52.1	1.62	18.5	2.24	11.9	.007
HF	51.3	2.16	24.8	3.04	36.9	<.001
VL	63.5	1.84	17.2	2.69	2.50	.47
Average	58.4					

Table 4a: Filter 2 Without Glare

Observer	Proportional Loss	Critical Ratio of Loss	Probability of Chance Occurrence
AM	.774	4.96	<.001
LP	.680	7.02	<.001
HF	.729	6.00	<.001
VL	.693	8.52	<.001
Average	.719		

Discussion

We may well inquire to what extent the effect of the yellow-tinted glasses differs from the effect of neutral glasses of equivalent luminous transmission. We have not run the comparative experiments required to answer this question in an entirely satisfactory manner. However, it will be instructive to compare the results of the present tests with inferences we can make from the Blackwell and McCready data.

Presumably, we can evaluate the effect of neutral glasses reasonably well by considering their effect to consist simply in a reduction in background luminance without a change in target contrast. What we require is a set of iso-contrast contours, curves in which target size and background luminance are related for constant contrast. To obtain these from the data in Figure 1, we first interpolate for constant background luminance. We obtain the curves exhibited in Figure 4. These may be used to provide the iso-contrast contours shown in Figure 5. To predict the loss in angular subtense of the target as a result of a filter, we require only the luminous transmission of the filter.

In the present case, we compute that the transmission of Filter 1 for 2360° K. radiation is .859, employing the ICI luminosity values. The corresponding value for Filter 2 is .686. We construct iso-contrast contours for the target contrasts involved in the present experiments. These are exhibited in Figure 6. We indicate the background luminance without filters on each iso-contrast contour by a vertical line designated "NF." Then, we indicate the background luminance reduced by the filters by vertical lines marked F1 for Filter 1, and F2 for Filter 2. The loss in target subtense may be computed from values of threshold target subtense corresponding to the several background luminances. The computed proportional losses for the four experiments are as follows:

Experiment	Proportional Loss	
	Predicted	Obtained
1	.89	.943
2	.72	.801
3	.81	.917
4	.66	.719

We note that our predictions rank the four experiments correctly, but that we predict more loss than was actually obtained. We cannot be certain whether or not these results imply that the tinted filters have effects different from equivalent neutral filters. For one thing, different observers were involved in the present experiments and in those reported by Blackwell and McCready. The present targets were 6 x 1 rectangles, whereas the targets in the other experiment were circular. Half of the present experiments involve glare, whereas the other experiments were conducted entirely with a uniformly bright background. (The differences between predicted and obtained losses are not apparently different, however, for experiments 1 and 2 involving glare and for experiments 3 and 4 which did not involve glare.)

It seems relatively safe to expect that any filter will reduce target detection distances. We are probably justified in concluding that our method of predicting losses in detection at low luminance due to filters gives us a useful

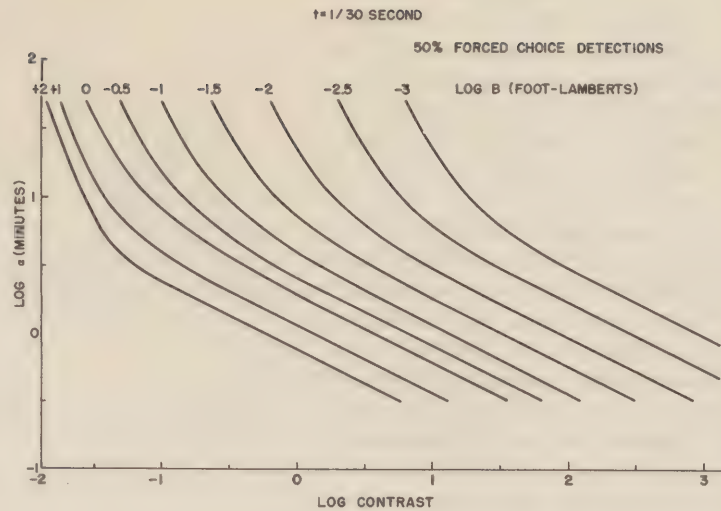


Figure 4. Interpolated Curves from the Blackwell and McCready Data.

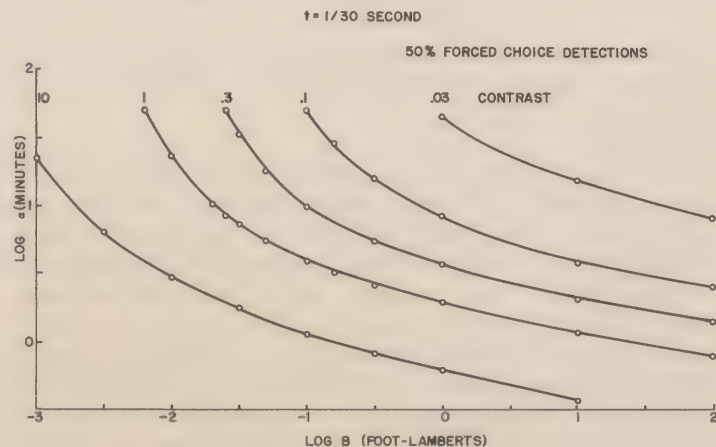


Figure 5. Interpolated Curves from the Blackwell and McCready Data.

estimate of the magnitude of the effect. Predictions with this extent of validity will materially reduce the necessity for empirical evaluation of the many filters which may at some time be proposed for use in night driving.

We may use our prediction method to illustrate one very important aspect of this problem. The proportional loss due to the use of the tinted filters will depend upon the precise conditions under which they are used. It is clear from Figure 5 that the proportional loss is greater the lower the background luminance, and greater the higher the target contrast. The conditions of our experimental evaluations of the filters seem to represent a fair sample of conditions to be expected in night driving, but conditions exist under which greater loss is to be expected. For example, for target contrast of 1.0, predicted losses of .81 for Filter 1 and .59 for Filter 2 are associated with lower luminance than the one used in the experiments. At target contrast of .339, predicted losses of .79 for Filter 1 and .57 for Filter 2 are associated with lower luminance than the one used in the experiments.

It is to be noted that the transmission of the yellow-tinted glasses will be somewhat less under conditions of night driving than under the conditions of our tests. The color temperature of automobile headlights is 3050°K . The transmission of Filter 1 for this quality of illumination is .850; the transmission for Filter 2 is .675. We therefore expect the losses in target detection distance to be somewhat greater under actual use than under the conditions of our tests, all other factors being equal.

Discussion:

Dr. Spragg commented that the National Research Council Committee on Highway Safety Research would be very interested to learn of Dr. Blackwell's research on yellow-tinted glasses. At a research conference of this Committee in Washington last summer, the question of yellow-tinted glasses was discussed, and it was the opinion of those present that yellow glasses would have deleterious effects. However, no data were available at that time.

Mr. Olson stated that, in his opinion, two points needed to be demonstrated before one could conclude that the yellow-tinted glasses should not be used for night driving. The first of these is that detection, rather than visual acuity, is the visual task of interest in night driving. The second is that visual performance is related to the motor vehicle accident rate. Mr. Olson stated his opinion that, although some tasks of night driving involve visual detection, others involve visual acuity. With regard to the second question, Mr. Olson stated his belief that it has to be demonstrated that visual performance and highway accidents are closely related. For example, a recent study reported by the Highway Safety Division of the North Carolina Department of Motor Vehicles failed to show a relation between the visual acuity of drivers and motor vehicle accidents. If differences in visual acuity do not show up, one might argue that differences in detection capacity related to the use of tinted glasses would not have significance in terms of accident rate.

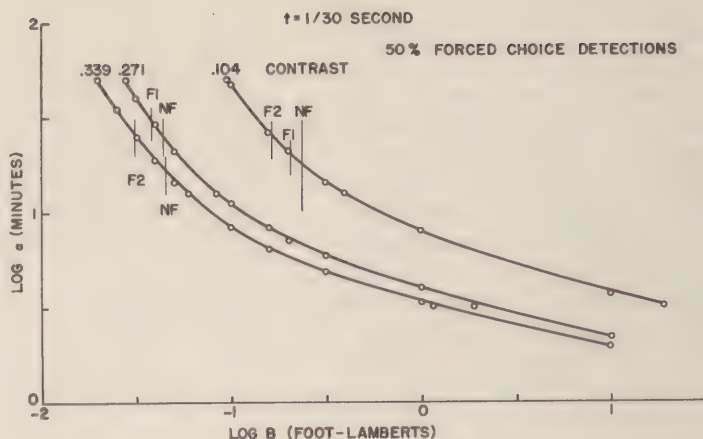


Figure 6. Interpolated Curves from the Blackwell and McCready Data. See text for explanation.

- Dr. Blackwell emphasized his belief that the critical visual task in night driving is visual detection. Pedestrian and highway obstacle accidents are most frequent causes of night accidents, according to the NRC Committee on Highway Safety Research. These accidents clearly seem to involve detection rather than the resolution of fine detail. So far as Mr. Olson's second objection was concerned, Dr. Blackwell stated his belief that visual performance would be related to highway accidents if all other variables were held constant. To be sure, other variables are of major importance and hence it may be difficult to demonstrate differences due to visual performance without extremely large samples of data, but this does not imply the differences are not real.
- Dr. Fry asked whether yellow-tinted glasses might not be helpful in night driving by reducing possible ultraviolet radiation effects upon dark adaptation.
- Dr. Blackwell stated that his research was not concerned with ultraviolet radiation problems. He said that it seemed to him unlikely that ultraviolet would be important in the night driving case, due to the intervention of headlight and windshield glass, to say nothing of the fact that ultraviolet effects upon vision are small, if they exist at all.

THE LIMITING CAPABILITIES OF UNAIDED HUMAN VISION IN AERIAL RECONNAISSANCE*

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1. Introduction

The ability of the human eye to recognize objects on the ground from moving aircraft is affected by the observer's speed and altitude, by atmospheric and lighting conditions, by the contrast formed by the object and its background, by the size and shape of the object, by impediments to vision imposed by the structure of the aircraft, and by the environment in which the observer finds himself. It was decided to explore limiting visual capabilities by ignoring any limitations imposed by environment or by aircraft structure. Established techniques for the prediction of the limiting range at which objects can be visually detected (see references 1 through 4) have been extended by means of new theory and new data (reference 5) and guided in application by reconnaissance experiments at model scale. Target recognition has been studied during these experiments, and correlations between recognition and detection have been found for the circumstances and targets encountered in visual aerial reconnaissance.

The end product of the work is presented in Table 1, which shows the maximum altitudes from which visual recognition of various military objects is possible from high-speed aircraft. The data applies only to a nearly cloudless day when the atmospheric clarity is such that the meteorological range is 10 nautical miles. The selection of this particular weather and lighting condition was purely arbitrary. Other conditions, such as clearer weather, hazier weather, overcast skies, twilight, moonlight, snow-cover, etc., could have been explored by continued calculation had time permitted. The contribution to be expected of optical aids to vision (binoculars, etc.) could also have been explored.

2. Results

Table 1 shows the maximum altitude at which a given level of detail is recognizable from an aircraft in straight and level flight at ground speeds ranging from 300 to 3000 miles per hour. At all altitudes below the maximum altitude, the specified object can be seen; above the maximum altitude, it is unlikely that the object will be observed. Examples are carried through for each of two contrasts: the higher inherent contrast, 0.6, is a contrast condition which describes olive drab troops and vehicles in the California desert, as found by measurement on models used by the Visibility Laboratory during reconnaissance experiments. The lower inherent contrast of 0.33 is representative of olive drab troops and vehicles on black pavements, some dirt roads, and green grassy fields.

* This paper, written after the meeting, includes data and calculations not available on the meeting date. It is presented in lieu of a summary of the actual remarks made by Dr. Duntley in the belief that this treatment is more valuable than a recount of the research in its earlier stage. The paper will also be published by the Visibility Laboratory of the Scripps Institution of Oceanography of the University of California as a report under Research and Development Project NS 714-100, which is supported jointly by the United States Navy and the United States Air Force. The research was performed under contract NObsr-43356 between the Bureau of Ships and the University of California.

TABLE 1

Maximum altitudes, 100 feet and over, from which visual recognition of various levels of detail for two values of inherent contrast, is possible from high-speed aircraft on a nearly cloudless day with a meteorological range of 10 nautical miles. Blank spaces in the table indicate that the object will not be seen.

Level of Detail	Velocity					
	300 mph		600 mph		1200 mph	
	Contrast		Contrast		Contrast	
	0.60	0.33	0.60	0.33	0.60	0.33
Man Lying Down	3300	1400	310	--	--	--
Mortar	1530	540	400	--	--	--
Man Standing Up	2000	1300	1600	810	720	120
Motorcycle	5300	2800	3100	1200	910	170
Jeep	9000	5400	6100	2500	2600	540
Tank-Wide	> 10,000	8200	9500	5600	6300	2400
Tank-Long	> 10,000	> 10,000	> 10,000	8200	9000	4200
					500	230

Comparison of maximum altitudes for the two different contrast cases reveals that visual reconnaissance capabilities are but little affected by speed when the target contrast is high. The speed effect becomes much more pronounced, however, when low contrast targets are the reconnaissance objective. Good camouflage (low contrast) appears, therefore, to be highly rewarding as a counter measure against high-speed aerial reconnaissance. At speeds higher than those available today the speed effect is pronounced even on objects of moderately high contrast. At 3000 miles per hour, for example, reconnaissance observers will be unable to see individual soldiers, motorcycles, or jeeps, although they can report the presence of some larger vehicles such as tanks. Objects larger than tanks, such as houses, barns, villages, and lakes will always be visible for the weather and lighting conditions assumed for these calculations.

3. Level of Detail

At the request of the Air Force the data has been tabulated in terms of a quantity which has been called "level of detail." No simple correlation exists between the dimensions of a complex three-dimensional object and its area projected in the direction of the observer. (See Section 7.) The projected area of a tank, for example, depends upon the inclination of the observer's line of sight, upon the orientation of the vehicle, and upon the nature of its shadow.

Thus the term "level of detail" does not imply projected area, but rather the projection of the specific target with a specific orientation as seen from the given altitude, with the observer an appropriate distance away from the target. Since the appropriate distance needed for detection and recognition varies with speed, the projected area of a given target varies with speed as well as altitude. For this reason it was found to be meaningless to make an altitude versus level of detail plot of Table 1 with velocity as a parameter.

Any level of detail scale which results in a smooth curve for one velocity produces sharp discontinuities in curves pertaining to other velocities. As an illustration, compare the data for a man standing up with a man lying down for the two lower velocities. For 300 miles per hour the man lying down can be seen at higher altitudes because his projected area increases with altitude, while for the 600 miles per hour case the man standing up can be seen at higher altitudes because of the requirement for sufficient observation time to permit recognition. The same reversal in maximum altitude with velocity occurs in the case of the two orientations of a tank, and can be explained in a similar manner. Thus the concept of level of detail, although useful in applying these results to the practical problems of aerial reconnaissance, does not readily lend itself to the construction of graphical plots.

4. Reconnaissance Experiments at Model Scale

Direct experimental data on the ranges at which observers can detect and recognize specific targets from low-flying, high-speed aircraft were obtained from experiments at model scale. These experiments were obviously easier to arrange than actual flight tests; moreover it was possible to simulate speeds up to 3000 miles per hour, thereby providing significant information not obtainable from full-scale tests.

Eight observers were asked to make observations from moving automobiles, and to detect, recognize, and report the presence of vehicles and men distributed along a wide sandy strip adjacent to a desert highway. Four cars, each with one passenger and one driver, performed the test. Road speeds of from 12.5 miles per hour to 125 miles per hour, corresponding to flight speeds of 300 miles per hour and 3,000 miles per hour respectively, were used, with intermediate simulated flight speeds of 600 and 1200 miles per hour. In the first experiment commercially available toy soldiers and toy vehicles were

employed. They were of such a size that the height of the eye above the road afforded by ordinary automobiles corresponded to a flight altitude of 100 feet.

The course was selected in such a direction that the shadow of the troops and vehicles fell away from the observer and therefore did not contribute appreciably to the appearance of the objects. Inherent contrast of the vehicles and troops was measured with a portable brightness photometer and found to be -0.6 . Thus the observing conditions corresponded to those represented in the higher contrast cases shown in Table 1.

Approximately 60 toy soldiers and 15 toy vehicles were dispersed throughout a course one mile in length. The observers had no previous knowledge of the exact location of the targets along the course, the number of targets and their location being changed before each run. After every trip through the course each observer reported the number and kind of objects which he had seen. Despite minor individual differences and learning effects, it soon became apparent that the reconnaissance scores were not appreciably affected by the speed of the automobile, when the course was run at simulated speeds of 1200 miles an hour or less. At 3,000 miles an hour, however, it was observed that no soldiers were seen, but observers correctly reported about one half of the vehicles. It will be noted that this result is predicted by the data in Table 1.

Additional experiments using contrasts of -0.35 and -0.9 and a simulated speed of 1200 miles per hour produced results that did not differ appreciably from those described above. Clearly, troops and vehicles having contrast of ± 0.35 or more will not be lost due to present and near future aircraft speeds, at least from extremely low altitudes.

The experiments were continued with objects of such a size that an altitude of 300 feet was simulated for the same flight speeds described previously. The measured contrasts were -0.4 and -0.2 . A significant difference was observed for reconnaissance score made for the different contrasts. In the high contrast case the average error was higher than had been previously noticed but did not seem to be affected by speeds up to 1200 miles per hour. In the low contrast case the error increased noticeably with speed. These results concur with the predictions of Table 1.

Recognition and detection distances were determined by asking observers to drive down the road and drop a sand bag from the car when they first sighted a lone soldier. These trials were executed for all the contrasts and simulated altitudes previously discussed and at a simulated speed of 1200 miles per hour. Recognition distances were also determined by asking the observers to drop a sand bag when they felt they recognized the target as a soldier. These operations were repeated several times and the results found to be reproducible within a few feet.

5. Criterion of Recognition

Visual detection of the presence of a distant object is a predictable process dependent upon the physical factors which determine the stimulus, upon the contrast thresholds of the observer, and to some degree upon his training and his motivation. Recognition of the object, on the other hand, is a far more complicated matter involving not only detecting the target but accumulating information about it until the object is identified. There exist no established techniques for the prediction of the limiting circumstances under which recognition is possible; there is grave doubt whether such a technique can be evolved for general application. In special instances, however, wherein the observer is fully oriented in terms of perspective, expectation, and experience it appears possible to develop a criterion for the threshold of recognition.

The model-scale experiments described in the preceding section demonstrated that objects can always be detected before they can be recognized. No fixed ratio was discovered,

however, between detection and recognition distances. Rather, it appears that the rapidly moving observers required an interval of observation between detection and recognition and that the duration of the interval is a constant, independent of flight speed, altitude, or nature of target. It was found that those reconnaissance observers who produce the highest scores do not watch the target continuously during this interval; their eyes search other parts of the scene but return to the target for brief, steady views. In this way information concerning the target is accumulated by the brain, a threshold of recognition being achieved after approximately 2.7 seconds. This experimental finding has been incorporated into the calculations which led to Table 1 by introducing the requirement that the target must be visually detectable for 2.7 seconds before the aircraft passes over the target. In this way the criterion of recognition is expressed in terms of the criterion for detection, and the predictions contained in Table 1 are, therefore, based upon detection calculations for which there are established techniques and visual data of high reliability.

It should be pointed out that detection directly beneath the aircraft gives no recognition time whatever. Clearly, detection must occur at some time interval before the plane reaches the target. The selection of 2.7 seconds is the result of experimental findings and is, therefore, subject to revision on the basis of further evidence. Any such revision would alter the values reported in Table 1, but a very major revision would be required to change the trends indicated by the table.

6. Criterion of Detection

Before maximum detection ranges and altitudes can be calculated, an effective stimulus duration must be assigned. Due to the rapid relative movement between the aircraft and the target the observer has several choices of observing technique. Considerable attention was given to the technique employed by the various observers who participated in the field experiments previously described. The highest scores in reconnaissance were achieved by those who concentrated their search at approximately the detection threshold distance and allowed the motion of the vehicle to provide the primary scanning mechanism. After a target had been detected in this way, brief stationary views were used to build up the mental impression, as described under the discussion of recognition in the preceding section of this report.

It is believed that any conscious step-wise technique for detection search will produce reconnaissance scores inferior to those obtained above, unless the location of the target is known relative to some major, easily visible landmark. In general, the best detection search procedure is believed to be represented by a semi-static eye aimed by experience approximately at the detection threshold distance. Sweep is then due to the motion of the aircraft, and the effective duration of the stimulus is represented by the time required for the image to pass over any given point on the retina. Predictions of detection ranges based upon stimulus duration calculated in this way were in excellent agreement with detection ranges found by experiment during the reconnaissance trials at model scale.

7. The Prediction of Maximum Reconnaissance Altitudes

In view of the preceding discussion, the effective duration of the target stimulus has been taken as the time interval required for the image of the object to pass over any given point of the retina of the eye if the eye is held steady and the relative motion between the airplane and the target is responsible for the motion of the image.

Referring to Figure 1, if the stimulus duration due to the translation of the front vertical face of the object across a point on the retina is $\Delta t'$, then the total stimulus duration Δt is given by:

$$\Delta t = \Delta t' + \frac{w}{v}$$

where w is the dimension of the target parallel to the direction of flight, and v is the velocity of the reconnaissance aircraft.

The assumption, discussed in Section 5, that 2.7 seconds of flying time are needed between detection and the time the observer is directly over the target, determines the length of the baseline of the right triangle whose hypotenuse is R . During the time $\Delta t'$ the target possesses an apparent motion along the ground through a distance $v\Delta t'$. From similar triangles,

$$\tan \theta = \frac{h}{v\Delta t'} = \frac{H}{2.7v}$$

where h is the height of the object, and H is the altitude of the observer. Figure 1 is not drawn to scale; in all cases $H \gg h$.

Solving for $\Delta t'$:

$$\Delta t' = \frac{2.7h}{H}$$

Thus:

$$\Delta t = \frac{2.7h}{H} + \frac{w}{v} \quad (1)$$

Equation (1) expresses the relation between the effective stimulus duration, and the dimensions of the object, the velocity of the observer, and his altitude. Once the effective stimulus duration is known, the minimum angular subtense needed for detection can be specified for any given value of contrast and any light level. Data supplied by the Vision Research Laboratory of the University of Michigan (reference 5) and plotted in Figure 2 give the minimum angular subtense α , necessary for the visual detection of uniform circular targets as a function of their apparent contrast and stimulus duration for full daylight. Using the stimulus duration given by (1) and the graphs in Figure 2, the minimum angular subtense necessary for detection at any aircraft speed for any object can be calculated as a function of altitude and contrast.

In an earlier paper the Visibility Laboratory (reference 4) has described an improved nomographic method for finding the apparent contrast of distant objects along inclined paths of sight under virtually any circumstances of weather and lighting. These nomographs were used to calculate apparent contrasts for a near cloudless day having a meteorological range of 20,000 yards. Inherent target contrasts of 0.60 and 0.33 were used throughout these calculations, as previously explained in Section 2.

To apply the data shown in Figure 2, the projected area of a given target must be evaluated in terms of an equivalent circular disk.* The equivalent angular subtense of a specific target as a function of orientation and sighting range can be calculated from the diameter D of the equivalent circle and the sighting range R by means of the equation $\alpha = 3438 D/R$, where α is to be expressed in minutes of arc. The diameter D of the equivalent circle can be found from the geometry of Figure 3, which shows a target of height h , width w , and breadth a , as seen from an elevation angle θ . The distance between the observing airplane and the target is large enough so that rays from the target entering the observer's eye are essentially parallel. If $A \sin \theta$ is the projection of the

* It is generally believed (see references 1 and 2) that no target is more detectable than a circular disk of equivalent area and that entirely negligible differences exist, for example, between data for a circular object and for a 4-to-1 rectangle of the same area under the conditions of the present problem.

target as seen from the airplane, then

$$A \sin \theta = \pi \left(\frac{D}{2} \right)^2$$

and:

$$\alpha = \frac{3438 x^2}{R} \sqrt{\frac{A \sin \theta}{\pi}}$$

$A \sin \theta$ can be expressed in terms of the dimensions of the object in the following way:

$$A \sin \theta = a (h \cos \theta + w \sin \theta)$$

Moreover, referring to Figure 1,

$$R = H \csc \theta$$

Therefore

$$\alpha = \frac{3880 \sin \theta}{H} \sqrt{a(h \cos \theta + w \sin \theta)} \quad (2)$$

and θ is a function of v and H .

The maximum altitude at which the target can be seen is that altitude at which the α available for detection no longer exceeds the α necessary for detection. It is found by the usual bracketing procedures necessary in visibility problems where visual thresholds defy analytical expression and where appropriate nomographs have not yet been constructed. The results appear in Table 1, which represents the end product of the work described by this report.

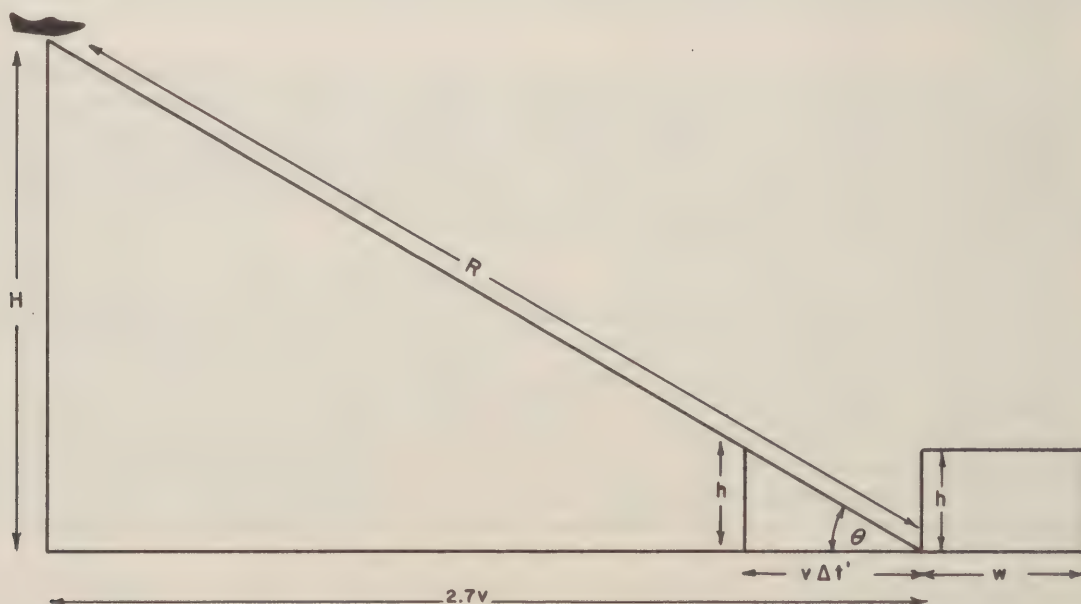


Figure 1.

SUBTENSE IN MINUTES OF ARC

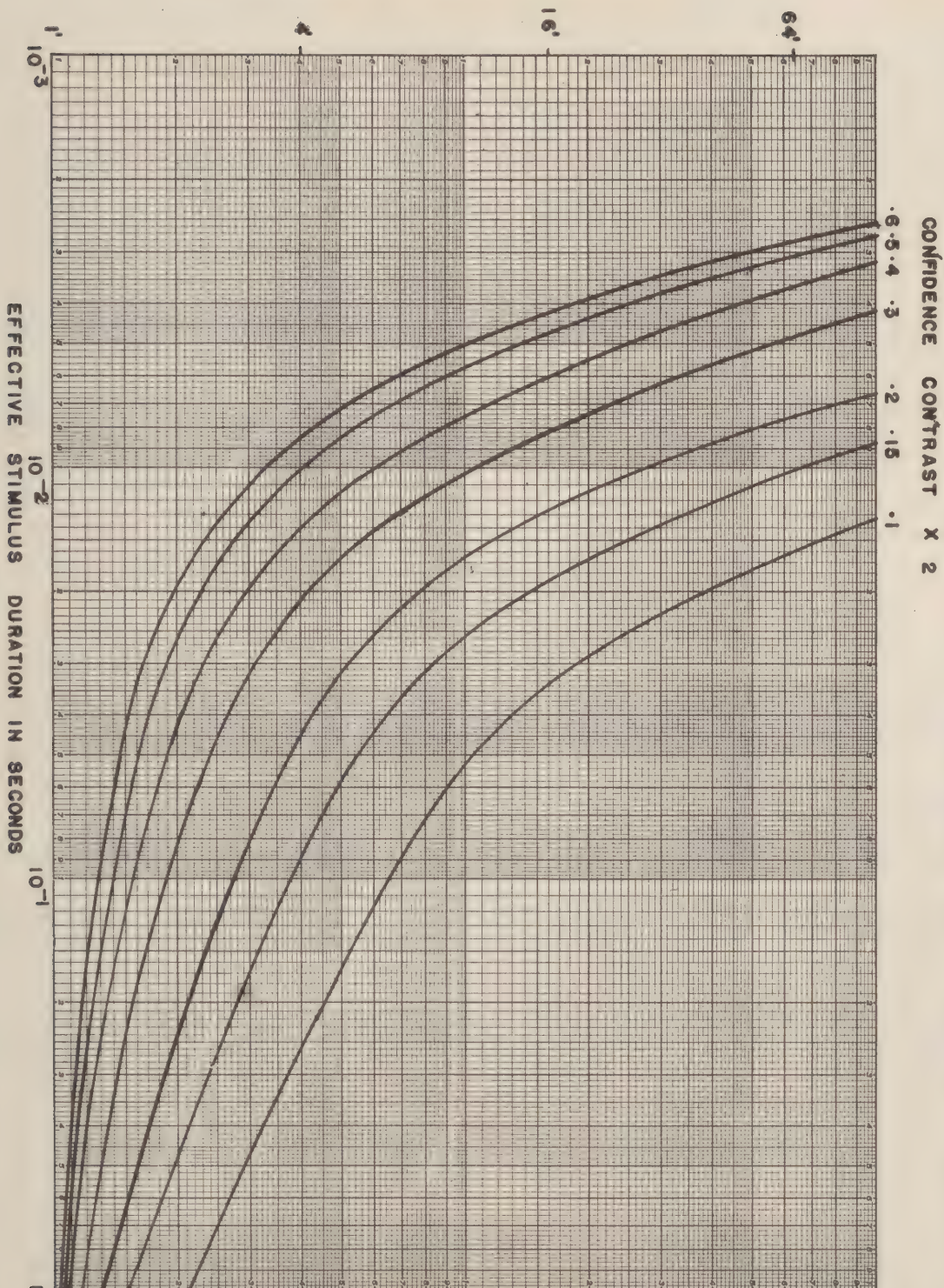


FIGURE 2

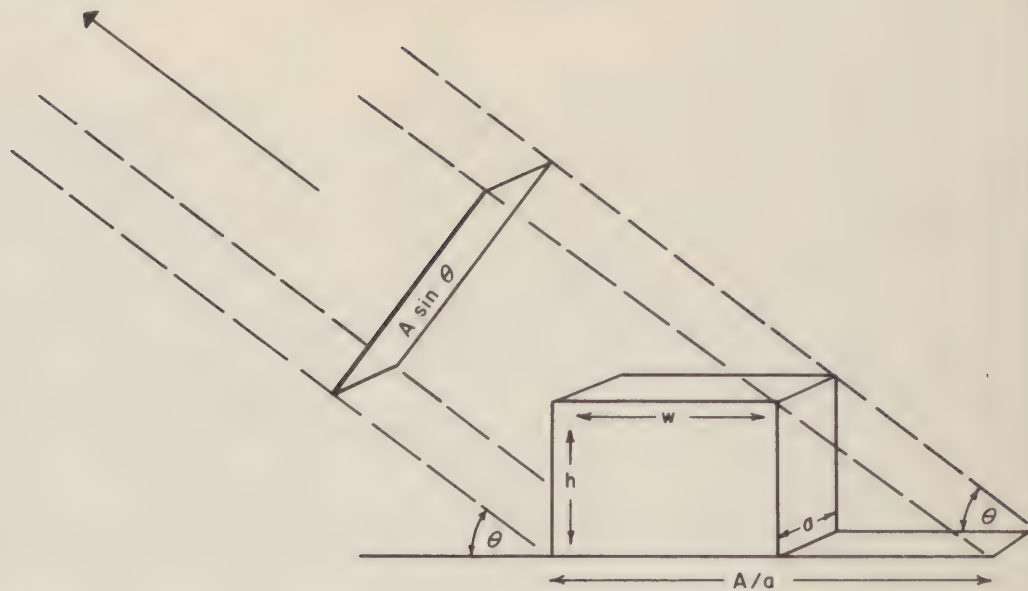


Figure 3.

References

1. "Visibility Studies and Some Applications in the Field of Camouflage", Volume 2, Summary Technical Report of Division 16, NDRC (CONFIDENTIAL) (1946).
2. "The Visibility of Distant Objects", Seibert Q. Duntley, J. Opt. Soc. Am. 38, 237 (1948).
3. "Vision Through the Atmosphere", W.E.K. Middleton, Univ. of Toronto Press (1952).
4. "Recent Advances in the Prediction of Visibility from Aircraft", Seibert Q. Duntley, Minutes and Proceedings of the Armed Forces-NRC Vision Committee, 29th meeting, p. 109 (1951).
5. "Foveal Contrast Thresholds for Various Durations of Single Flashes", H. R. Blackwell, Minutes and Proceedings of the Armed Forces NRC-Vision Committee, 21st meeting (1952).

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ANNOUNCEMENT OF THE MADRID MEETING
OF THE INTERNATIONAL COMMISSION OF OPTICS

Dr. Stanley S. Ballard announced that the International Commission of Optics will hold its third regular congress in Madrid, Spain, during April 1953, in connection with the activities in celebration of the 50th anniversary of the founding of the Royal Spanish Society of Chemistry and Physics. The business sessions of the congress will be restricted to official delegates from the several participating countries. However, there will also be an open symposium on Optical Problems of Vision, organized by the Spanish society, with Professor J. A. Artigas as Chairman and Professor J. M. Otero as Secretary, and held at the Institute of Optics in Madrid. This meeting will extend over the three-day period 15 to 17 April, and will be featured by invited papers presented by Messrs. Stiles of England, Granit of Sweden, Le Grand of France, and Wald of the United States. Those who wish further information about the symposium should contact the Chairman of the U. S. A. National Committee of the International Commission of Optics, Professor Stanley S. Ballard, Tufts College, Medford 55, Massachusetts.

REPORT OF THE WORKING GROUP
ON ILLUMINATION AND DARK ADAPTATION

Prepared by William S. Verplanck, Chairman

This group was appointed for the purpose of preparing a critical review of the literature on dark adaptation as a function of antecedent conditions of illumination, with emphasis on wavelength. As we saw the job, it involved the preparation of an exhaustive bibliography on the topic, the review of papers cited in this bibliography, with the preparation of evaluative abstracts of each, and finally, the publication of a paper summarizing the status of knowledge on this and closely associated topics. We anticipated that we would be able to complete this program over a period of months. As a consequence of a number of circumstances which will become clear in the course of this report, it has proved impossible for us to carry this program through to completion. This report, then, will describe the work achieved to date, and the arrangements we have made for the completion of the job.

In planning the attack on the program we decided to devote our first efforts to the bibliography and then to tackle the actual reading and abstracting according to a priority system set up in terms of (a) the probable relevance of titles in the bibliography to the topic with which we were concerned, and (b) the probable quality of the research reported in this paper. We set up a simple coding system, and each title examined was classified on a scale of 1 to 5, where "1" was applied to papers whose title clearly indicated their relevance, and where "5" referred to papers that might contain data important to us, but probably not. The second classification labelled as "A" indicates papers originating from investigators and laboratories of first-class reputation, "C" was applied to field-studies carried out under conditions not likely to yield data of lasting significance. These systems were used only to determine the order in which papers would be sought out for reading. When we did read papers, the classifications were, of course, of no further significance; and, as it proved, many papers had been mislabelled.

Bibliography: The initial working bibliography was obtained from a careful examination of all titles listed appropriately in the following bibliographies:

- (1) Fulton, J. M., Marquis, D. G., et al. A bibliography of visual literature, 1939-1944 and supplement, 1945, N. R. C. Washington.
- (2) A further typewritten supplement to the above, of all papers in the files of the USN Medical Res. Lab., New London, Conn., not listed in the above; prepared in 1946, -47, or -48, by Mrs. E. B. Cook.
- (3) N. M. R. I. 's References on Vision (A list, by title, of Luckiesh's reprint file, prepared by Frank Moss).
- (4) The chapters on vision and sensory physiology in The Annual Review of Physiology of recent years.
- (5) Psychological Abstracts (since Vol. I).
- (6) Bibliographies of reviews, such as Chapanis' chapter in Human Factors in Under-sea Warfare, and Judd's and Bartley's chapters in Handbook of Experimental Psychology, and Berry's work on tests of night vision.
- (7) Several scattered bibliographies issued, from time to time, by such units as the Committee on Aviation Medicine, of the N. R. C.

(8) The index of the reprint file of W. J. Crozier.

(9) As each paper was read, its list of references was checked against the bibliographic card file, and new titles were collected in this way.

When (1) through (8) above had been searched, and after some titles had been obtained in (9), we had the following number of titles in each of the five "relevance" categories.

Category	Number of Titles
1	53
2	25
3	42
4	94
5	43
Total	257

Reading and Evaluation

A. When the bibliography was assembled, a list of titles inaccessible in Cambridge was made up. These included reports of studies made during the war by military and similar research organizations, which either were never published, or were published in obscure series. Many of these were classified. This list was sent to the Secretariat of the Vision Committee, which was able to produce some of them from its files, but by no means all of them. It was clear that a number of papers would remain inaccessible, unless one of us went to search the files of reports that are scattered through various military establishments. Many other papers are in obscure journals. It has not been possible for either of us to take the several weeks of full-time work in Washington and elsewhere that will be necessary to track these papers down, and to read and to abstract them.

B. We proceeded to read and to abstract the literature available locally. This again, proved to be an extremely inefficient procedure when undertaken on a part-time basis. When one is able to work at such a job for only an hour here, a morning there, and so on, the time required for the completion of the work becomes excessively great--a matter, in fact, of years rather than of weeks. Once again, it became clear that the proper execution of the functions of this Working Group can be expected only if the full-time, or at least the half-time, work of at least one person is devoted to the review. Neither of us could undertake this job. At the time this state of affairs was recognized, we had abstracted and evaluated 32 papers.

Present Arrangements

After a certain amount of conferring with several people, including the participants in the Vision Committee's Conference on Problems related to Chart Reading under Red Cockpit Illuminations, held in New London on September 30th, we had apparently reached an impasse, where no one seemed available to undertake to finish the job, with the possible and reluctant exception of members of Dr. Blackwell's staff. Dr. Mason Crook, one of the participants in the New London Conference, then recounted the state of affairs to his colleagues at Tufts University, and a happy solution has been achieved.

The Laboratory of Applied Experimental Psychology, of Tufts University, holds Contract AF 30(602)--199, Griffiss Air Base, Rome, N. Y., covering research entitled "A determination of the pre-exposure tolerance of the dark-adapted eye." Part of the program includes the following three items:

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- (1) To prepare a bibliography on dark adaptation.
- (2) To prepare an annotated bibliography on dark-adaptation as a function of (a) intensity, (b) duration, and (c) wavelength (in that order) of pre-exposure.
- (3) To write a critical evaluation of the work annotated in (2) to the extent that time and money permit.

This part of the Tufts program is obviously close to the function of this Working Group, and if both continued, the two groups would needlessly duplicate a good deal of effort.

After conferring with Dr. Blackwell, and by arrangement with Dr. Joseph W. Wulfeck of the Tufts Laboratory, we have turned over to the Tufts Laboratory our full bibliography, with all the work we have done to date. They, in turn, will execute the terms of their contract, and will incidentally provide the Armed Forces-NRC Vision Committee with the product of their labors. Their review might not be as complete as one might like, nor will it necessarily be in the form of a conveniently read review article. But the Tufts group will get the major, and the most important, part of the work completed and in the hands of the Committee, in a fraction of the time which would be required if this Working Group attempted to continue its work to completion.

It is, therefore, recommended that this report be accepted by the Committee, and that this Working Group be dissolved.

William S. Verplanck, Chairman
Richard T. Mitchell

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REPORT OF WORKING GROUP ON AIRFIELD TAXIWAY LIGHTING AND DESTINATION MARKING SYSTEMS

Prepared by Paul M. Fitts, Chairman

The following comments represent opinions of the Vision Committee Working Group with regard to the project conducted by Dunlap and Associates for the Bureau of Aeronautics, U. S. Navy, with respect to airfield taxiway lighting and destination marking systems. The Working Group has a good impression of the work being done by Dunlap and Associates. It is hoped that the comments presented here will be found useful by Dunlap and Associates.

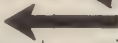
Taxiway Lights

The tentative proposals in regard to taxiway lights appear satisfactory and we have no suggestions in regard to this topic.

Taxiway Turn-off Markers

Turn-off markers appear to be an especially important problem in view of the great importance of getting aircraft off the runway as soon as possible. The working group tends to favor the use of closely placed blue lights rather than amber lights to mark the edges of the taxiway at the point of turn-off from the runway. The pattern or position of the lights, rather than their color, would in this case be the distinctive clue to the pilot and probably would be sufficiently distinctive. The use of blue for all taxiway lights appears to us to have an advantage of simplicity and should simplify the landing field pattern as viewed both from the air and from the ground.

In regard to the use of arrows to indicate the turn-off, it is our feeling that a single arrow on the near side of the exit may be sufficient. Pilots would "go around the arrow" in making their turn-offs. This usage conforms to that now employed on U.S. highways.

It is suggested that the new-style arrow being used on most modern highways, which looks something like this  be considered in lieu of the old-style arrows which look something like this . The relative legibility of these two types of arrows should be tested under airport conditions, or else data should be obtained from the Highway Research Board in Washington as to why highways are now changing over to the new-style arrow.

It is our feeling that the turn-off arrow is the most important airport surface marker in terms of the distance at which it needs to be seen. It needs to be seen at approximately twice the distance required by any other marker.

The arrow indicating the last exit from the runway might be supplemented by the word 'last' or the word 'end' on an adjacent sign.

We are not certain how important it is to indicate the angle of the turn-off. What proportion of runway exits are approximately ninety degrees to the runway? What is the consensus of pilot opinion as to the importance of indicating the turn-off angle? This question probably should receive further study.

Destination Markers

Our interpretation of Dunlap and Associates' data is that military pilots are not especially concerned with having destination markers placed on the taxiways. Perhaps the location

of these markers should vary, depending on whether the airport is used chiefly for civilian or military flying.

Of the various criteria for evaluating the effectiveness of different kinds of destination markers, it is our belief that the free association test is the most important. For this reason, it is our feeling that abbreviations or short words are probably the best type of symbol. Such short words or abbreviations are only slightly more complex than some of the proposed geometrical symbols, and probably have better legibility. We suggest that Dunlap and Associates consider the use of either three- or four-letter symbols for the various destinations. The current practice of commercial airlines in regard to the use of three-letter symbols for marking destinations on luggage is perhaps an indication of the effectiveness of this kind of symbolism. Below is a table indicating some of the possible three- or four-letter symbols that could be tried out for common destinations.

Destination	Three-letter symbol	Four-letter symbol
U.S. Navy	USN	Navy
U.S. Air Force	AF	USAF
Military	MIL	MILT
Ramp	RMP	RAMP

Destination	Three-letter symbol	Four-letter symbol
Non-scheduled	NSK	NOSK
Commercial	CML	COML
Park	PRK	PARK
Fuel	GAS	FUEL
Express	XPR	XPRS
Customs	CST	CUST
International	INT	INTL
Passenger	PSR	PSGR
Hangar	HGR	HNGR
Visitor	VST	VSTR

For economic reasons the adoption of a standard size for destination markers seems highly desirable. Whatever the size of this marker, it should be possible, of course, to put two or three standard-size markers end-to-end, thus increasing the length of the space available for the destination symbol.

Legibility

It has already been mentioned that the legibility required for destination markers is much less than that required for the turn-off arrow. However, the important thing is that the arrows and destination markers be visible through a windshield that has water on it, and under conditions of poor ground visibility. The crucial tests of legibility will be those from actual taxiing aircraft both at night and in the daytime under low visibility conditions.

It is our feeling that Dunlap and Associates could make a valuable practical and basic research contribution to an old legibility problem, the question of the relative effectiveness of black on white vs. white on black printing, assuming that in both cases transmitted light will be used. The question here is: Given a sign of a fixed area, is it better to transmit light to represent the symbols, or to represent the background; in either case, what are the optimum dimensions of the symbol and the background? It is obvious, in the case of the lighted background, that the symbol must not go all the way to the edges of the available area.

In the case of printed symbols there is also the question of whether it is better to use all-capital printing or to use both upper- and lower-case letters. In regard to this particular problem and also in regard to the design of the turn-off arrow, we suggest that Dunlap and Associates consult with Dr. Ted Forbes, Executive Secretary of the Highway Safety Committee of the National Research Council. Dr. Forbes has worked on highway markers for many years and just recently completed an extensive project sponsored by the state of California on the design of destination and exit markers for multi-lane arterial highways. He studied, among other things, the relative legibility of upper and lower case printing on fixed-area signs. It strikes us that the problem of the automobile driver in looking for the exit from a large arterial highway under bad weather conditions while traveling at sixty miles an hour is quite comparable to the legibility problem faced by the aircraft pilot. Dr. Forbes may also have some useful suggestions in regard to other aspects of the airport marking problem.

Pilot Opinion

It is our feeling that the pilot opinion data collected by Dunlap and Associates are quite useful although a certain amount of interpretation is necessary before using them. For example, it may be valuable to make a further breakdown of the data in regard to the differences between civilian and military pilots, and in regard to the specific type of flying done by the pilots. For example, what are the opinions of the pilots who have actually used an Aldis Lamp vs. those who have seldom or never used one?

Compatibility

We are sure that The Bureau of Aeronautics is well aware of the various plans for future developments of airport surface control, such as the use of airport surveillance radar and the use by the airport controller of voice directions or airport signs to direct the movement of surface traffic. We feel it is quite important that the new system of taxiway and destination marking be compatible with any future requirements imposed by further developments in airport surface control. We believe that Dunlap and Associates should check with the various agencies that are planning for this future system and solicit their comments on the adaptability of the proposed taxiway and destination marking systems to the future requirements for airport surface control.

W. E. Kappauf
A. C. Williams
P. M. Fitts, Chairman

REPORT ON INTERNATIONAL NOMENCLATURE
FOR DESIGNATING VISUAL ACUITY

Kenneth N. Ogle, Chairman
American Committee on Optics and Visual Physiology

INTRODUCTION

The Committee on Optotypes* of the International Council of Ophthalmology has been interested in the adoption of a decimal system to designate visual acuity that would be standard for international use. Dr. Conrad Berens, a member of that committee, asked that an expression of opinion on that problem be obtained from the American Committee on Optics and Visual Physiology before a decision is made and before final recommendations are made to the International Federation of Ophthalmologists. Accordingly, at the meeting of the American Committee in October, 1951, a special sub-committee was appointed to explore the possibilities of working out "the geometrical and decimal systems together in a practical manner."

The members of that committee are:

Col. Victor Byrnes, Randolph Field, Texas
Alfred Cowan, M.D., Philadelphia, Pennsylvania
Lt. Cmdr. Dean Farnsworth, U.S. Submarine Base, New London, Conn.
Gerald Fonda, M.D., Millburn, New Jersey
W. B. Lancaster, Boston, Mass.
James Lebensohn, M.D., Chicago, Ill.
Kenneth N. Ogle, PH.D., Mayo Clinic, Rochester, Minn., Chairman
Louise Sloan, Ph. D., Wilmer Institute, Baltimore, Md.

The discussion of the problem and the recommendations by the members of this committee have been made entirely by correspondence.

CONCLUSIONS

Briefly the conclusions of the majority of the members of the committee are as follows:

(1) Although among ophthalmologists and optometrists visual acuity charts are used primarily in determining refractive errors of patients, the design of these charts should be such that determinations of visual acuity itself could be made with reasonable accuracy.

(2) The Snellen notations, such as 20/30, 5/6 or 14/16, are admissible only if the visual acuity determinations have been made at 20 feet, 5 meters or 14 inches, respectively. The numerator of the fractional representation should indicate the distance at which the visual acuity was measured. To apply the designation 20/20 to a visual acuity measured at 10 feet or at 14 inches is incorrect usage, and should be avoided.

(3) Although there is as yet no published data which give experimental proof that a geometrical progression in the sizes of the letters of successive lines of the visual acuity chart represents a physiological attribute of different visual

*A sub-committee of the American Committee on Optics and Visual Physiology in the American Medical Association.

acuties, the majority of the committee members felt that this type of progression was desirable. A physiological basis for a geometrical progression might be found in the relationship between uncorrected refractive errors and visual acuity. The data on this relationship that are available in the literature tend to show such a geometrical progression, but the spread of the data between the various experimenters is such that the magnitude of a geometrical progression cannot be satisfactorily determined.

(4) The geometrical progression in which the ratio of the size of the letters of a given line on the chart to that of the preceding line of smaller letters is of the order of 1.26. This appears to be satisfactory and has also historical precedence. Several members of the committee felt that a rigorous adherence to a geometrical progression was not necessary or important. Several visual acuity charts currently in use (e.g., the A.M.A. visual chart) are not designed for rigorously geometrical progression. On the other hand, those members of the committee with a military and research point of view believed that a geometric progression should be strictly adhered to. The charts should be made accurate, though perhaps the clinical designation need not be precise.

(5) A careful study shows that it is impossible to work out a uniform decimal system (on the basis that the decimal is equal to the reciprocal of the visual angle in minutes of arc, i.e., to the numerical value of the Snellen fraction) for designating the visual acuity of charts and preserve a geometrical progression of the sizes of the letters of successive lines. Only if the decimals (or numbers) used have an arbitrary basis can such a system be employed. These are then useless for conversion or interpolation to other visual acuity scales unless tables are consulted.

(6) Besides the above fact there is the important objection to the decimal system that a given decimal always tends to connote a percentage of normal vision. One tends to compute mentally a percent "loss" of vision at once. This implication is quite untrue and is often dangerously misleading.

(7) The decimal system as well as the Snellen notation has the basic assumption that 1.00 represents "normal" vision. This is a misstatement of fact. The "normal" visual acuity of healthy eyes is probably better than 1.00. A large percentage of the population has visual acuities that exceed 1.00, although the "average" visual acuity for the whole population may turn out to be less than 1.00. It is unfortunate that the term 20/20 and its designation in decimal form has become a fetish in the popular mind.

(8) The underlying factor in all visual acuity testing is the resolving power of the eye. The letters of the usual test chart and the International test object, the Landolt ring, are designed to measure insofar as possible that resolution. The members of the committee almost unanimously and strongly feel that visual acuity should be stated in terms of the quantity that is actually measured. The Advantages of such a system are obvious. Such a designation would be automatically international. It can be readily understood by all, including the layman. It removes the fetish of the 20/20 concept, for there is no implication of a "normal" visual acuity. It is equally useful for the clinician and for the research worker. Conversion to any of the presently used systems, meters or feet, centimeters or inches, can be made mentally. A visual acuity threshold of 2.3 would be 20/46 in the English system, or 5/11.5 in the metric system. One need only multiply the numerator--the test distance--by the visual acuity angle to obtain the denominator. Only lack of present usage and unfamiliarity argue against the

adoption of visual angle. A start in the right direction would be to designate each line in the test chart in both the conventional system and in visual angle. This has already been done in the newly designed Armed Forces-National Research Council visual acuity test chart.

(9) Finally, it was felt by several members of the committee that the particular choice of letters in the lines of the visual acuity chart was a much more serious problem, but this lay outside the scope of the present committee.

RECOMMENDATIONS

The Sub-Committee, on the basis of discussion and of the considerations presented in this report, makes the following recommendations:

(1) A decimal system for designating visual acuity should not be standardized for international use.

(2) For the designation of visual acuity, serious attention should be given at once to the adoption of the visual angle of resolution in minutes of arc of the component parts of the test letters of the chart. Such a designation is a direct statement of what is actually measured.

(3) A geometrical progression in the sizes of the letters of successive lines of the chart is desirable. However, no particular geometrical progression should be standardized. The progression rate should be chosen according to the particular needs for a given chart.

(4) In the event that the recommendation for designating visual acuity by the visual angle of resolution is not immediately acceptable (and it would perhaps take time and the work of many to make it acceptable), no standard international designation system, decimal or otherwise, should be adopted. The present decimal system is understood generally, irrespective of the meter or feet systems. There is nothing to be gained by adopting a standard decimal system.

GENERAL DISCUSSION

Introduction

At the outset it was not exactly clear what was expected of this committee since the charge to it was "to work out the geometrical and decimal systems together in a practical manner." Doctor Lancaster wrote then: "...all that [would be] needed is to label the charts with both d/D numbers and the same values reduced to decimals by dividing d by D.*..... Such a simple matter can hardly be the purpose of the delegation of the International Federation of Ophthalmologists. A possible interpretation is: to select a series of sizes of letters or characters to be recommended for the chart manufacturers, these to be labeled both ways."

More to the point, it appeared that the task of the committee was to obtain a majority point of view regarding a proposal to standardize (1) a particular mode of designating visual acuity and (2) a particular graduation of steps in letter size for the visual acuity charts. These two problems are interdependent. Moreover, a number of fundamental problems are involved in these. Before making recommendations for the adoption of a particular notation or graduation for visual acuity charts for international usage, these problems should be stated and insofar as possible studied. Essentially this is what the committee has done, and perhaps it may have gone farther into the general problem than was necessary for the immediate purpose.

Many ophthalmologists have insisted that the visual acuity test charts are primarily for clinical use (1) to determine the effect of certain ocular diseases on visual acuity and (2) especially to assist in the determination of the refractive correction for patients. The visual acuity itself is then not important until the final refractive correction is approached in the refraction examination. The exact manner in which the letters of successive lines of the chart decrease in size would for this purpose be relatively less important.

The majority of the members of this committee, however, felt that the design of test charts should be such that reasonably accurate determinations of visual acuity itself could be made. Certainly the fundamental basis for the design of such charts or for the designation of visual acuity in any international standardization should not handicap the research worker or those who must select personnel on the basis of visual acuity (such as may be necessary for industry or for the armed forces).

A uniform decimal scale or fractional designation of visual acuity requires some type of a uniform gradation in the sizes of the letters of successive lines of the test chart. There seems to be almost universal agreement that this gradation should approach that of a geometrical progression, that is, a gradation in which the size of the letters of one line bears a constant ratio to the size of the letters in the preceding (or succeeding) line of the chart. As stated by Lancaster: "the series of letter sizes on the chart (as shown long ago by Ewing and Green^{8,9}...) should be so chosen that the jump from one line to the next smaller is always the

*Actually the decimal designation should be defined as the reciprocal of the visual angle (of resolution) expressed in minutes of arc.

same (20%) and hence from one line to the next larger is always 25%. Experience has shown the Ewing-Green plan is not only sound but eminent-useful." Such a method of preparing a visual acuity chart gives sizes of test letters of successive lines on the chart which increase in a geometrical progression. Instead of making all the letters on a given line of the chart the same size, it may be desirable to design the test chart so that successive letters increase in size. Again the gradation in size of successive letters should be in geometrical progression.

The following questions are then pertinent:

1) Are there any theoretical or experimental bases for making the sizes of the letters of the visual acuity chart increase in a geometrical progression?

2) If so, what should be the rate of the geometrical progression?

3) It would then follow, what should the designation of these steps be for a simple and practical scale for designating visual acuity that could be used internationally?

Geometrical Gradations

To say that the gradation of sizes of the letters of successive lines of the visual acuity test chart increases in a geometrical progression means that there is a logarithmic relationship between them. More explicitly, if A is the visual angle (minutes of arc) subtended at the eye by the letters of a given line on the chart, and if we define the number of this line or step in the chart by S , then

$$A = R^S \quad \text{------(1)}$$

In this, R is a constant, and is the ratio of the size of the letters of one step to that of the letters of the preceding line. For if A_1 is the size of the letters of line number S , and A_2 is that for the next higher line on the chart, number $(S + 1)$, then the ratio

$$\frac{A_2}{A_1} = \frac{R(S + 1)}{R^S} = R \quad \text{------(2)}$$

It follows then from (1) that

$$\log A = s \quad [\log R]$$

This means that if the logarithms of the visual angles of the letters of successive lines of the test chart are plotted against the step numbers of the lines, a straight line graph is obtained, the slope of which is $\log R$.

Thus in figure 1, there are illustrated the scales proposed by Green (1867), for which $R = \sqrt[3]{2} = 1.26$ (the size of the letters of each successive line is 26% larger than that of the preceding line, or 20% smaller than that of the following line); Javal¹² (1878) and Blaskowicz³ (1923), for which $R = \sqrt{2} = 1.41$, and that used for experimental purposes during the last war by the A. G. O. for which $R = \sqrt[4]{2} = 1.189$.

The gradation in test lines of many currently used charts does not conform to a geometric scale. For example, in Figure 2 are shown the scales used in the Project-O-Chart (American Optical Company), the A.M.A. test chart of visual efficiency, the Vision Committee new Armed Forces chart, and the Monoyer¹⁸ (1874)

decimal scale which Landolt (1887) essentially used.

The higher the value of R , the fewer will be the steps on the chart between the visual angles of 1 and 10 minutes of arc (Snellen visual acuity 20/20 to 20/200) and hence the coarser the measurement of visual acuity. The A.G.S. scale has the lowest gradient of all scales so far proposed. This scale permits a finer measurement of visual acuity, which necessitates more steps and hence a larger chart.

Any number of different geometrical series could be worked out, all depending upon the particular choice of R . In particular, suppose we want a chart with a range of visual angles r (say 1 to 10) for a given chart, and suppose we want n steps within that range; then the ratio R of the size of the letters of any line to that of the preceding line will be $\sqrt[n]{r}$.

Visual Acuity Designations

The fundamental basis of visual acuity is the minimum separable or the minimum angle of resolution—the ability of the eye to perceive a small interruption of continuity in a test pattern. The threshold of this perception would be the smallest visual angle under which this gap or series of equally sized gaps of the test detail can be discriminated. We need not here go into the matter whether in the use of any test type factors other than pure resolution are involved.

In the design of characters for testing visual acuity by chart, historical precedence set by Snellen has made the visual angle of one minute of arc the starting point. If the constituent parts of the test characters (letters, numbers, etc.) subtend a visual angle of one minute of arc, and these characters can just be discriminated by the subject, his visual acuity is said to be "normal." While many individuals have better acuity thresholds than one minute of arc, clinically speaking, if the threshold is no better than 1 minute, the eye has "defects sufficiently pronounced to easily established," for example, refractive errors, central scotomas, amblyopia, cloudy media, etc.

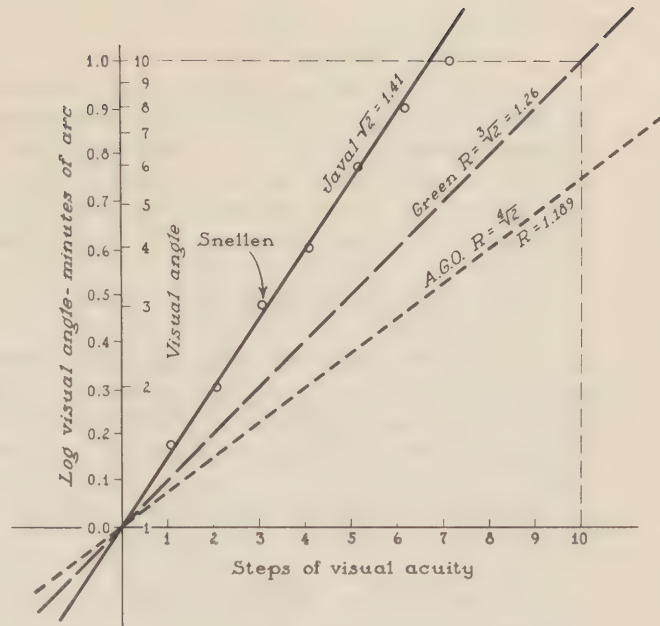


Figure 1.

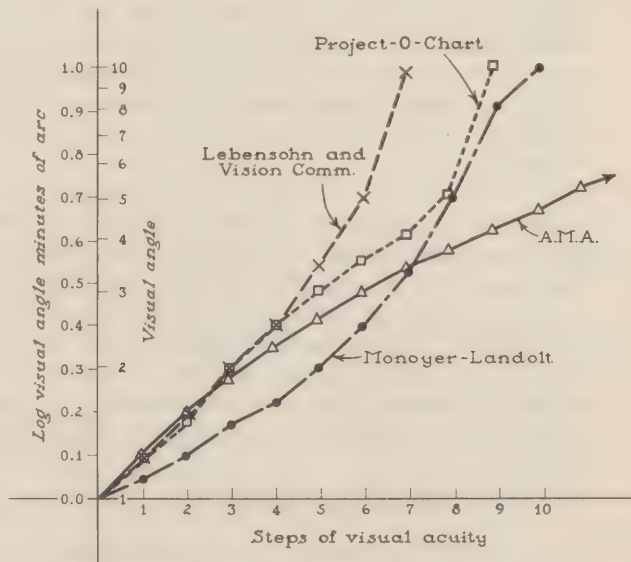


Figure 2.

1. Fractional Form.

If letters (or test figures) the constituent parts of which subtend a visual angle to the eye of one minute of arc can just be discriminated, the vision of that eye is said to be unity, $V = 1$; if that angle is $1/2$ minute of arc, its vision is said to be $V = 2$; if the visual angle is 2 minutes of arc, the vision is said to be $V = 1/2$. Thus the visual acuity is said to be represented by the number (fraction) which is the reciprocal of the smallest angle of resolution in minutes of arc.

2. Snellen Notation.

The well-known Snellen designation for visual acuity V is the fractional notation $V = d/D$ in which d is the visual distance at which letters of a certain size can just be discriminated (the test distance) and D is the distance at which those particular letters would subtend one minute of arc.

When the Snellen notation is reduced to lowest denominator, it is equivalent to the fractional form given above.

A problem in the use of the Snellen notation is: Are we justified in using this notation, for example, 20/30 (or 6/9), to indicate the visual acuity when the test made was conducted at some other observation distance than 20 ft. (or 6 meters)? Should the numerator of the fractional form always indicate the visual distance at which the test was conducted, or can we use these fractions merely as names to identify a particular visual acuity? Are we really justified in using the same fractions for near (reading) and for distances? Lebensohn, 15, 16 for example, has used the Snellen 20/X equivalent notation on his near vision test charts. Probably most refractionists would say "no" to this last. But we talk about a 20/30 distant vision acuity, when it may have been measured on a test chart at 12 feet.

A second problem concerns the comparison of visual acuity for near vision with that for distant vision. If the acuity for distance is 20/30, a calculation is necessary to find that this corresponds to 14/21 when inches are used and the visual distance is 14 inches. From the point of view of many refractionists this problem of comparison of distant and near acuity is not so important since the distant and near scales are separate aspects of the refraction problem. However, such comparison may be important, for example, in testing malingersers, and checking the adequacy of a given refraction.

3. Decimal Notation.

Since first suggested by Monoyer in 1874, a decimal system has frequently been proposed which would be more readily comprehended by all regardless of the units of length used (feet or meters, inches or centimeters, distant or near vision). The decimal notation is the reciprocal of the visual angle in minutes of arc, and this is also equal to the numerical value of the fraction notation as well as to the Snellen notation. This decimal system is quite generally used internationally and with certain writers it is considered the most suitable system. The objections to the decimal form are:

a. It tends to connote a percentage of vision (and difference from unity as percentage loss of vision) which is erroneous.

b. A uniform and simple decimal scale that at the same time permits a

geometrical progression in the sizes of the letters of successive lines is impossible. That is, one cannot have a geometric gradation and at the same time make $20/20 = 1.0$, $20/40 = 0.5$ and $20/200 = 0.1$. In order to adhere rigorously to a geometrical progression in the sizes of the letters of the chart, uneven decimals result.

The value of the decimal notation is that one can easily (mentally) convert to the Snellen notation in either metric or English units. No reference tables are necessary.

4. Other Types of Notation.

a) In order to avoid the "percent of vision" implication of the decimal system, it has been proposed to multiply each decimal notation by 10, so that $20/20 = 10$ and $20/200 = 1$. Such a system has been employed with the Orthorater.

b) An arbitrary scale of 1 to 10 was suggested by Armaignac¹ in 1906, namely:

Visual Angle (min.)	1.00	1.25	1.60	2.20	3.00	4.00	5.00	6.60	8.20	10.00
Snellen	20/20	20/25	20/32	20/44	20/60	20/80	20/100	20/132	20/164	20/200
Armaignac	10	9	8	7	6	5	4	3	2	1

c) Based upon an analogy with the specifications of lens power by diopters, Blaskowicz³ (1923) has suggested units of visual acuity which he calls "oxyopters." Oxyopters are defined as $60 \div$ visual angle in minutes of arc. Thus using a geometric progression in which $R = \sqrt[3]{2}$

Visual Angle	0.6	0.75	1.0	1.25	1.73	2.28	3.00	4.00	5.25	7.00	9.20
Snellen	20/12	20/15	20/20	20/25	20/35	20/45	20/60	20/80	20/100	20/140	20/180
Oxyopters	100	80	60	48	35	26	20	15	11.5	8.5	6.5

d) In order to be completely divorced from preconceived concepts about normal visual acuity, a research project conducted during the war under the A.G.O. arbitrarily selected units for a visual acuity scale based upon the formula

$$U = \log_2 2^{10}/A$$

in which A is the visual angle in minutes of arc. This formula gives a geometrical progression (called by Farnsworth⁷ the "kappa" scale) with $R = 1.18$ and is in part as follows:

Visual Angle	0.5	0.6	0.7	0.84	1.0	1.2	1.43	1.67	2.00	2.40	2.7	3.33	4.0	etc.
Snellen	20/10	20/12	20/14	20/17	20/20	20/24	20/28	20/33	20/40	20/48	20/55	20/67	20/80	"
A.G.O.	44	43	42	41	40	39	38	37	36	35	34	33	32	"

e) Colenbrander ⁴ believed that the decimal scale exaggerated changes in visual acuity in the range of poorer vision, as compared to changes in the better acuity range. He suggested that to equalize more nearly the steps of the scale and obtain a more "valid" visual acuity, the square root of the decimal form visual acuity should be used (see Table I).

TABLE I
SUGGESTED SIMPLIFIED GEOMETRIC
PROGRESSION [AFTER GREEN*]

STEP	VISUAL ANGLE	SNELLEN		DECIMAL	"VALID" DECIMAL	MODIFIED VALID
		ENGLISH	METRIC			
4a	.40	20/8	6/2.4	2.5	1.58	1.6
3a	.50	20/10	6/3	2.0	1.41	1.4
2a	.63	20/12	6/4	1.6	1.25	1.2
1a	.80	20/16	6/5	1.25	1.12	1.1
0	1.00	20/20	6/6	1.00	1.00	1.0
1	1.25	20/25	6/7.5	.8	.9	.9
2	1.6	20/32	6/10	.63	.8	.8
3	2.0	20/40	6/12	.5	.7	.7
4	2.5	20/50	6/15	.4	.63	.6
5	3.2	20/64	6/20	.32	.56	} .5 †
6	4.0	20/80	6/24	.25	.50	
7	5.0	20/100	6/30	.20	.44	} .4 †
8	6.3	20/125	6/38	.16	.40	
9	8.0	20/160	6/48	.12	.35	} .3 †
10	10.0	20/200	6/60	.10	.32	

* For which $R = 1.26$

† These three compromises reduce the number of lines of the test chart by 3.

Bases for a Geometrical Progression

Although there appears to be some general agreement that the sizes of the letters of successive lines on the test chart should increase by a geometrical ratio, theoretical and experimental bases for such a progression are by no means clear.

a) Lythgoe¹⁷ has published data which give the percent of correct answers in the discrimination (resolution) of the gap in a series of Landolt rings of varying sizes. If one plots the percentage of correct answers on probit (probability) graph paper against the logarithm of the visual angle of the gap in each case, a consistent straight line is found. This indicates that the probability of discriminating the gap is proportional to the logarithm of the visual angle, and as such suggests a geometrical progression in the sizes of the characters of the test chart. However, these data pertain only to an individual with a given visual acuity. Data are necessary which show that individuals in two groups whose visual acuities are in entirely different ranges are each normally distributed with respect to a logarithm of the visual angles of the same test chart. While such data may exist, they have not been described in the literature.

Attempts have been made to devise a scale of graduated sizes of test letters which would make the distribution of the visual acuities of the population in general a normal one. It was, for example, found by van Beuningen² that the frequency of 1190 observers between the ages of 20 and 35 distributed according to visual acuity tested with a letter chart, when plotted against the reciprocal of the visual angles, approximated a normal distribution. While a logarithmic progression assists in normalizing the curve, there is still too high a proportion of subjects in the 20/15 to 20/20 range. There is no reason to expect that such a normalizing scale can exist because of the anatomical limits (a limiting barrier) to the visual acuity in this region.

b) According to Javal, if the normal eye can resolve letters of a given size at one distance, but another eye can only discriminate the same letters at half the distance, it is illogical to write that the vision of the second eye is only 1/2. Since the angular area of the letters has been increased four times, he thought the vision should be written 1/4. There would be a constant ratio in the areas of letters in successive lines of a test chart designed on this basis, and such a scale would be a geometrical graduation. The problem is again what should be the particular rate of progression. Suppose we begin with the usual 20/20 line or visual angle of one minute of arc, and make the letters of the next line according to the present 20/25 line (visual angle = 1.25 minute). This procedure, of course, at once specifies the ratio $\underline{R}$ [equation (1) above], for if $\underline{a_1}$ and $\underline{a_2}$ are the areas of the letters of successive lines whose visual angles are $\underline{A_1}$ and $\underline{A_2}$, then according to this scheme

$$\frac{\underline{a_2}}{\underline{a_1}^2} = \frac{\underline{A_2}^2}{\underline{A_1}^2} = \frac{1.25^2}{1.00^2} = 1.562$$

but since $\underline{R} = \underline{A_2} / \underline{A_1}$,

$$\underline{R} = \sqrt{1.562} = 1.25$$

This scale of gradation is of course essentially the same as that of Green and of Ewing ($\underline{R} = 1.26 = \sqrt[3]{2}$).

c) Visual acuity and uncorrected refractive errors. The data that relate visual acuity with uncorrected ametropia (myopia in particular) as reported in the literature might provide an experimental basis for the rate of progression. Data available so far are considered by some workers not suitable as a basis for a visual acuity scale. However, the data appear to show a trend for both myopia and hyperopia. The data of the following experimenters have been used here:

- 1) 1920, Laurance¹⁴ (no source of data given)
- 2) 1945, Eggers⁶ (basis 6000 refractions)
- 3) 1945, Hirsch¹⁰ (64 myopic students)
- 4) 1945, Crawford,⁵ et al. (160 myopes)
- 5) 1951, Rubin,²⁰ et al. (1105 simple myopic eyes)

When the logarithm of the visual angles is plotted against the corresponding diopters of myopia, as shown in Figure 3, a linear-like trend is suggested. Only the data of Hirsch fail to show this trend, but his data on only 64 subjects cover a range of myopia 0.5 to 4.00 diopters in 0.5 diopter steps. Rubin et al. dealt with the problem statistically, and perhaps their data are the more important. In comparing the data of these writers one must keep in mind the differences in the test scales used, in the method of defining the groups according to refractive error and according to the fixed lens steps available, and in the intensities of illumination used, etc. The greatest discrepancies in the results of the several studies appear in the groups with the lower refractive errors. Nevertheless, the trend of the data in general, if we leave out those of Hirsch, seems consistent.

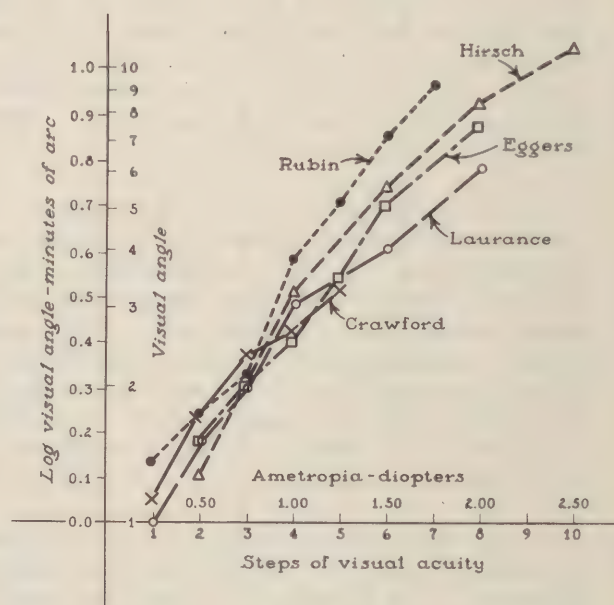


Figure 3.

The abscissa then corresponds to steps on a visual acuity scale, in terms of 0.25 diopter ametropia. When the method of least squares is applied to these different sets of data, one obtains for the values $\bar{R}$ and the intercept of the best fitting line, the following:

<u>Experimenter</u>	<u>$\bar{R}$</u>	<u>Intercept</u>
1. Laurance	1.273	0.925
2. Eggers	1.245	1.150
3. Hirsch	?	?
4. Crawford, <u>et al.</u>	1.291	0.973
5. Rubin, <u>et al.</u>	1.416	0.837

The average value of R for these four sets of data is 1.31. The average of R for these data is then between that of the Green scale ($R = 1.26$) and that of the Javal (Snellen) scale ($R = 1.41$). The intercept of $0.974' = 58.4''$ is not far from the origin of the log graph, indicating acuity of 20/20 would exist for those without refractive errors.

There may be other ways of plotting visual acuity so that the data of these experimenters would appear linear.²¹ Because of this fact and the great variation in the results of different experimenters, one cannot be sure that the relationship between refractive errors and visual acuity constitutes evidence that a geometrical progression has a physiological and optical basis.

Choice of a Geometric Progression

A geometric progression that tends to give whole or simple numbers in the visual angle, in the Snellen notation or in the decimal notation, would be desirable. Such a scale actually is that already proposed by Green and by Ewing, in which $R = 1.26$. This scale also is not out of line with the suggested trend of the data for the visual acuity versus uncorrected ametropia. The gradation provides, therefore, an excellent compromise gradation. The scale is illustrated in Table I. The steps are numbered consecutively from the visual angle of one minute of arc, the steps for higher visual acuity would ordinarily be negative. The visual angles subtended by the letters of successive lines increase logarithmically and are such that the largest number of whole numbers are obtained in the series. The Snellen notations are also simple, though in several instances there has been some rounding off to the nearest whole number. The decimal notation is perhaps the least uniform. Inspection of this decimal scale shows that the steps are not regular and small changes in visual acuity have exaggerated importance in the poorer range of visual acuities.

Following the suggestion of Colenbrander, extracting the square root of these decimal notations (in the next column) tends to give a more uniform scale, except again for the poorest acuities. We could even simplify this part of the scale by reducing the number of steps here and by taking average visual angles in those steps whose notations are close together. Then differences of 0.1 give a uniform scale, except for the highest visual acuities. Even here it might be worthwhile to increase the number of steps to make this part of the scale also uniform with the rest. While this procedure does give a uniform scale, the notations are somewhat artificial and cannot be converted easily into other notations.

Designation of Visual Acuity

The desirable designation for visual acuity which would also be acceptable for international use should be based upon the following criteria:

1. Insofar as possible, the designation should conform closely to the quantities and factors of visual acuity that are actually measured. In most visual acuity tests the factor of discrimination is resolution and this is measured by the visual angle subtended by the interruption of contours in the test details.
2. The designation should be adaptable to any degree of precision and should be readily understood under any test conditions, whether used by the clinician or by the research worker.
3. The designation used should not be selected on the basis that the discrimination of a visual angle of one minute of arc represents "normal" visual acuity. All

of our currently used systems for specifying visual acuity are fundamentally based on this theory. Thus, 20/20 notation is to tell us that the individual at 20 feet discriminates the test details which a "normal" eye should discriminate at 20 feet. It is common knowledge that emmetropic eyes can discriminate detail subtending a visual angle of considerably smaller than one minute of arc. The median in the distribution of nearly 1,200 subjects in the age groups 20 to 35 was found by van Beuningen to be 53 seconds of arc. Thus a large proportion of these subjects were able to discriminate test characters which subtend much smaller visual angles than 50 seconds of arc. Thus the basis that a visual angle of one minute of arc represents normal visual acuity is erroneous.

4. The designation should not depend upon a particular gradation in the sizes of the letters of the test chart in order to obtain a uniform progression. A uniform decimal system does depend upon a particular gradation in letter sizes.

5. The designation used should be easily converted into any of the currently used systems of notation.

A study of the above discussion brings one to a consideration of the only logical designation of visual acuity--namely, the visual angle subtended by the critical details of the test character. Minutes of arc are the units easiest handled. (Centrads, the 1/100th part of a radian angular measure, has been suggested, but for the most part this necessitates the use of decimals, and centrads are not understood by many.)

The advantages of the visual angle designation are:

- a) It conforms to the actual quantity that is measured in the visual acuity test.
- b) It carries no connotation of what is "normal" visual acuity. It indicates the actual ability of the subject; what sized objects can be discriminated. Its use would inculcate a more accurate idea of visual function even to the lay person, and is not subject to the misinterpretations in other nomenclatures.
- c) It in no way implies a relationship to visual efficiency.
- d) Any scale of graduated sizes of letters or test characters in successive lines or areas of test charts can be designed.
- e) Visual acuities determined at different distances can be directly compared.
- f) Only one visual acuity scale is required, regardless of the acuity. Even the visual angle of "fingers at one foot" can be readily calculated.
- g) Visual angles can be easily converted into any of the presently used systems for designating visual acuity.
- h) It is a unit of measure of angle known throughout the world and hence is adapted for international use.

The disadvantages of the use of visual angle should also be mentioned, though these are not significant compared to the advantages. These are:

- a) In any geometrical progression for specifying the size of characters for a test chart, equal changes in steps in the high acuity range are not comparable with those changes in the poorer range of acuities.

- b) There may be at first some confusion between visual angle and the decimal notations.

It is suggested that each line on the visual acuity test charts be labeled with both the Snellen index and the visual angle in minutes of arc.

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ABSTRACTS

370. A Recording Atmospheric Transmissometer
Pearson, C. A.
U. S. Naval Research Laboratory
Washington, D. C. NRL Rep 3949
March 7, 1952 13 pp. (0)

"A photoelectric telephotometer, which measures the illumination produced at a known distance from a calibrated light source, was developed to record directly the total atmospheric transmission at night over a two-mile path in the visible region of the spectrum. The photoelectric telephotometer is battery operated, and all parts are placed in one box 60 x 9 x 9 inches which can be transported and set up easily for field use. A Variac, an ammeter, a 1000-watt voltage regulator, and 115-volt ac power are used with a 1000-watt projection-type lamp as the light source. The recording transmissometer was calibrated (a) with a 2360 K standardized lamp, and (b) by comparing it with a visual telephotometer. Eleven transmission measurements from 20% to 80% total transmission over a two-mile path gave an average deviation of $\pm 5\%$ from a one-to-one correspondence between the photoelectric and the visual methods. Accurate measurements outside these limits of transmission would require a shorter path for lower transmission and a longer path for higher transmission of the atmosphere."

371. Visual Acuity Tasks in a Submarine
Dimmick, Forrest L. and Dean Farnsworth
Medical Research Laboratory
U. S. Naval Submarine Base, New London, Conn.
10 October 1951 (R)

"A survey was made of the visual factors involved in all interior submarine tasks which an enlisted man may be required to perform. It was found that distances from which visual signals are viewed within a submarine are less than the standard acuity testing distance of 20 feet. Visual angles subtended by critical tasks are always larger than necessary for discrimination by 20/20 vision, taking into account the larger visual angles required under the lower illumination found in submarines. Clinical analysis resulted in two conclusions: (1) that comparable work in industry is adequately performed by personnel with 20/30 vision tested at the distance of the task, and (2) that individuals with exophoria of more than 5 prism diopters or with hyperopia of more than 3 diopters are unacceptable."

372. A Study of the Requirements for Letters, Numbers, and Markings to be Used on Trans-Illuminated Aircraft Control Panels
Part 5 - The Comparative Legibility of Three Fonts for Numerals
Atkinson, Wm. H., Lloyd M. Crumley, & Mariqn P. Willis
Naval Air Experimental Station, Naval Air Material Center, Philadelphia, Pa.
13 June, 1952 26 pp. (0)

"The present experiment was designed to evaluate the legibility of the forms for numerals developed in this laboratory. These numeral forms are compared to the forms embodied in Air Force-Navy Drawing 10400 and the font developed by Berger. The tests were conducted under conditions of red transillumination ranging from .10 to 3.30 footlamberts and under conditions of daylight illumination with intensities of 11, 24, and 34 footcandles. For the transillumination tests, the duration of the exposures was approximately 200 milliseconds,

while in the daylight tests the duration of exposures was 5 milliseconds. The transillumination tests employed 30 subjects while the daylight tests required 48 subjects.

"Where total errors are employed as the criterion, it has been found that under the conditions of the experiment the AMEL proposed form is superior to the other two forms with red transillumination or daylight illumination. In the analyses of the error scores for individual digits, the digits of the AMEL proposed series are not always significantly more legible than their counterparts in the other two fonts. However, it was found that where significant differences in error scores are obtained, it is always the AMEL proposed digit which produces the fewer errors when compared with a digit of one of the other two forms.

"As a result of this study, the digits of the AMEL proposed form are recommended for use in aircraft on plastic console panels."

373. Airline Pilot Questionnaire Study on
Cockpit Visibility Problems
Pigman, Geo. L. and Thos. M. Edwards
Civil Aeronautics Administration, Tech.
Dev. and Evaluation Center, Indianapolis,
Ind. Tech. Dev. Rep. No. 123
Sept. 1950 38 pp. (0)

"A questionnaire concerning vision problems from aircraft cockpits was distributed to approximately 6,000 airline pilots as a part of a broad study relating to cockpit visibility. About 1,342 of the questionnaires were completed and returned. This questionnaire included specific evaluation of vision characteristics of present aircraft in various maneuvers and directions of sight, and also covered general evaluation of different vision problems. The results of the questionnaire show that pilots are concerned about cockpit visibility problems and strongly believe that improvement is needed in most present aircraft.

"Analysis of the questionnaire data shows that vision cut-off angles for the different directions of sight may be defined in terms of windshield outlines which correspond to pilot ratings of adequate or excellent. In determination of these vision cut-off angles, the attitude of the airplane in various critical maneuvers must be considered. Reasonable accuracy appears to be obtained by this method, although knowledge of airplane attitudes in different maneuvers is not precise and could be improved through further investigation.

"Results of analysis of the questionnaire data are presented in relation to the various specific vision problems, and are combined into a general set of requirements which include vision cut-off angles, post arrangement, and allowable vision distortion. The results are not considered to be a final solution to the visibility problem, but offer a useful guide to the amount and quality of vision which will be considered suitable by the pilots."

374. Effect of Flashes of Light on Night
Visual Acuity Part 1
Fry, Glenn A. and Mathew Alpern
The Ohio State University Research
Foundation
WADC Aero Medical Lab. Wright-Patterson
AFB WADC Tech. Rep. 52-10
Nov. 1951 44 pp. (0)

"The purpose of the study was to find out the ability of the eye to see a dark object against a sky background at night after the eye had been exposed to a flash of light or a series of flashes. This capacity of the eye was measured by varying the width of a vertical

dark bar stretched across a circular bright patch 8° in diameter. A point 5° to the left of center of the patch was fixated with the right eye. The brightness of this patch varied from zero to 0.0107 ml. and was observed through a 2mm. artificial pupil.

"The major phase of the investigation was concerned with the effect of adapting to various levels of retinal illuminance the portion of the retina on which the image of the test object falls. It has been found in this phase of the study that a reciprocity exists between time and intensity of stimulation within a three-second interval, that is, the effect is dependent upon the product of time and intensity. Also within this interval of time intermittent stimulation was found to be equivalent to continuous stimulation when the product of time, intensity and number of flashes in the one case was compared to the product of time and intensity in the other.

"The second phase of the study deals with the effect of non-uniform distributions of brightness in the field of view. The effect of exposure to brightness in one part of the field of view upon the subsequent visibility in another part of the field of view is dependent upon the adaptation to stray light in the eye. The use of the Stiles-Holladay equation for computing the effects of a complex distribution of brightness in the field of view has been tested and found to be reasonably adequate."

375. Effect of Flashes of Light on Night
Visual Acuity Part 2
Fry, Glenn A. and Merrill J. Allen
The Ohio State University Research
Foundation
WADC Aero Medical Lab., Wright-Patterson
AFB WADC Tech. Rep. 52-10
Nov. 1951 34 pp. (0)

"The investigators have attempted to work out a method and to acquire the necessary data for predicting the course of constriction of the pupil of the dark adapted eye produced by a flash of any duration or a series of flashes involving a complex changing distribution of brightness in the field of view. To do this, one must know the distribution of luminance in the field of view and figure out how the impulses initiated in rods and cones in different parts of the retina summate both with respect to space and time to determine the pupil response.

"Records have been obtained of pupil responses to bright circular patches varying in diameter from 0 to 8° , representing levels of retinal illuminance ranging from 0 to 147,000 trolands and varying in duration from 0 to 3 seconds. Pupil responses have also been recorded for stimuli located at various distances from the point of fixation. The responses to two alternating stimuli have also been studied as well as the effect of exposing the bright patch so that its image falls on the optic nerve head. Care has been taken to see that these responses represent the response of the dark adapted eye.

"In the case of the dark adapted eye, stimuli applied to the central portion of the retina or at points away from the center varying up to about 35° are about equally effective in producing the pupil response. By varying either area or intensity of stimulation, it is possible to reach a limit beyond which the pupil cannot be made to constrict further. At intermediate levels, the pupil response is a function of the product of intensity and time within an interval of 0.2 seconds. For areas up to 8° , the pupil response is a function of the product of area and intensity.

"Further experimentation will be necessary to determine the precise role played by the regions of the retina directly stimulated and the elements in the remainder of the retina which are stimulated with stray light. Until this aspect of the problem is straightened out,

it will not be possible to formulate an adequate account of what happens when the duration is varied beyond a tenth of a second. Up to this duration, the pupil response is a product of the intensity and time."

376. 30 Degree Modified Slope-Line Approach-Light System
Warren, Roy E. and H. J. Cory Pearson
Technical Development Report No. 137
Civil Aeronautics Administration
Technical Development and Evaluation Center
Indianapolis, Indiana
February 1951 (0)

"This report presents the results of an investigation to determine the feasibility of widening the spacing between pairs of slope-line lights. This spacing is increased by decreasing the angle between the individual light bars and the horizontal. An installation was made in which the bars at the inner end of the approach path were set at 30° instead of 45° while the bars of the outer portion were left at 45° . This resulted in a definite break in the lines, which proved undesirable. In general, the sensitivity of the guidance furnished by the 30° bars is not as sharp as that furnished by the 45° pattern."

377. Thickness Adjustments of Glass Filters to Given Total Transmittance
von Schelling, Hermann
Report No. 193, Medical Research Lab.
U. S. Naval Submarine Base
New London, Conn.
10 March, 1952 (0)

"Investigators in the field of colored lighting are frequently faced with the problem of specifying the thickness of glass filters to obtain a certain transmittance and chromaticity. Either of two problems may arise: (1) One may wish to find the chromaticity and the total transmittance for a specified new thickness; or (2) to calculate the thickness which corresponds to a requested total transmittance. A new graph is provided from which the transmittances of filters of the same melt, but of different thicknesses, can be determined for any wave-length. Eight selected transmittance curves are given as a key for finding a good first approximation for the thickness of a filter which will produce a specified total transmittance. The procedure presented reduces this task to a routine which can be carried out without special training in color or mathematics. All of the tables and diagrams required in the calculation are provided with the exception of two handbook sources which are indicated."

378. The Effectiveness of an Abrupt Change in Texture-Density as a Stimulus for the Impression of Depth-at-an-Edge
Gibson, J. J. and J. S. Robinson
Hq. Human Resources Research Center
Air Training Command, Lackland AFB
AF Contract at Cornell University
February 1952 (0)

"The results indicate than an abrupt change in texture-density corresponds in direction to the impression of depth-at-an-edge whenever this impression occurs, but they do not suggest that the change in isolation is a sufficient and compelling stimulus for the impression. Only when the subject is set for, or expecting the possibility of, a quality of depth does the impression regularly appear under these circumstances. This result is to be contrasted with the perception obtained using the same experimental setup when the monocular viewing

tube was removed and the surfaces were viewed with two eyes and a mobile head. In the latter event (when an abrupt change in relative image-disparity and a corresponding change in relative motion at the edge were added to the change in texture-density) all observers invariably saw one surface clearly behind the other, both being clearly behind the circular window in the screen."

379. The Development of Airport Taxi Guidance Signs
Gilbert, Marcus S. and Robert E. Faucett
Technical Development Report No. 170
Civil Aeronautics Administration
Technical Development and Evaluation Center
Indianapolis, Indiana
June 1952 10 pp. (0)

"This report describes the development of an elevated sign or route marker for use along runways and taxiways in airport taxiway guidance systems. The sign, unlighted during the daytime and lighted at night, is conspicuous and legible from a distance of 500 feet under variations in visibility ranging from one-fourth mile up to an unlimited condition. Lighted translucent flush block letters make the sign visible and legible at night; these letters are outlined in black on a chrome yellow background to give the desired daytime effect."

380. The Development of an Airport Taxi Guidance System
Hemelt, Bernard A. and Marcus S. Gilbert
Technical Development Report No. 171
Civil Aeronautics Administration
Technical Development and Evaluation Center
Indianapolis, Indiana
June 1952 14 pp. (0)

"This report discusses the need for and development of a system of signs to furnish guidance by day and night to pilots who are taxiing on an airport. Basically the system consists of a number of conspicuous signs properly placed to identify intersections and turnoff points to specified destinations. The system described has been recommended for adoption as a Civil Aeronautics Administration Standard."

381. Index of Refraction Measurements with an Airplane Psychrograph
Overcash, Frank J.
WADC Aircraft Radiation Laboratory
Wright-Patterson AFB, Dayton, Ohio
AF Technical Report No. 6621
August 1951 38 pp. (0)

"An airplane psychrograph was used by the Aircraft Radiation Laboratory of Wright Air Development Center to obtain accurately the atmospheric index of refraction up to 10,000 feet in the Dayton, Ohio, area. Complete details of its use are given, with curves of experimental results. This instrument makes a continuous recording of the fine detail of the wet-bulb and dry-bulb temperature above freezing which is used with pressure to calculate index of refraction. These data show that the index profile follows closely the wet-bulb temperature profile in the Dayton, Ohio, area in the summer months. Index lapse rates greater than $30(n-1)10^6$ units per 100 feet were recorded at 7,000 feet. Actual index curves that conform approximately to what has been considered the standard were found to be the exception rather than the rule."

382. Luminance Thresholds for the
Resolution of Visual Detail
During Dark Adaptation
Brown, Jack L. and Clarence H.
Graham, Herschel Leibowitz,
and Howard B. Ranken
Columbia University
WADC, Aero Medical Lab.
Wright-Patterson AFB, Ohio
WADC Technical Report 52-12
Jan. 1952 14 pp. (0)

"Luminance thresholds for the visual resolution of various widths of alternating light and dark lines were determined at various times during dark adaptation. The finest gratings, representing high degrees of visual acuity, show only a single cone curve that drops from a high luminance threshold during the first moments of dark adaptation to a final steady level that is reached after about 7 to 10 minutes in the dark. Coarse gratings produce a duplex curve that shows an initial cone portion and a delayed rod portion. Visual acuity is a parameter that sets the position of a given curve on the log threshold axis. The higher the degree of resolution required, the higher the dark adaptation threshold. At a constant grating luminance, visual acuity rises rapidly to a maximum during dark adaptation; the higher the luminance, the earlier and more rapid the rise and the higher the maximum. Visual acuity increases at all dark adaptation times with increase in luminance. Implications of these findings for instrument lighting are discussed."

383. Tracking Performance on Combined
Compensatory and Pursuit Tasks
Senders, John W. and Marianne Cruzen
WADC Aero Medical Laboratory
Wright-Patterson AFB, Ohio
WADC Technical Report 52-39
Feb. 1952 14 pp. (0)

"A comparison has been made between compensatory and pursuit tracking for a one dimensional visual tracking task, and the functional relationship between tracking accuracy and the nature of the tracking task has been determined for various combinations of pursuit and compensatory tracking. The results indicate that important, as well as statistically significant, differences exist between compensatory and pursuit tracking, and that accuracy of tracking increases markedly as a function of the amount of pursuit component which exists in the task. However, a tracking task which has a pursuit component of 50 per cent or greater is not significantly different, in terms of time-on-target score, from a 100 per cent pursuit task."

384. Fixations During Day and Night GCA
Approaches Using an Experimental Instrument
Panel Arrangement
Milton, John L., Billy B. McIntosh and
Edward L. Cole
WADC Aero Medical Laboratory
Wright-Patterson AFB, Ohio
AF Technical Report No. 6709
Feb. 1952 35 pp. (0)

"This report is the seventh in a series of investigations of eye movements of pilots during instrument flight. The frequency, duration, and sequence of eye fixations made by 15 pilots when flying day and night GCA approaches with a new panel arrangement are sum-

marized. For purposes of comparison, data previously obtained with the standard Air Force panel arrangement during GCA approaches under day conditions are included. All conditions investigated showed that the air speed, directional gyro, gyro horizon and vertical speed are the most used instruments.

"Significantly more fixations were made during day GCA than during night GCA. The average length of all fixations was shorter during the day although not significantly so. The average length of fixation on some of the individual instruments, however, were significantly shorter during day GCA. The total number of fixations and the average length of all fixations were approximately the same for both the standard and the new panels. There were significant differences between numbers of fixations on some of the individual instruments. The length of fixations did not vary significantly for any of the instruments. Considering the results of this study and the results of other studies which show that the optimal spacing between instruments is short and horizontal, and that instruments in the top row tend to be fixated first and more frequently, the standard panel appears to represent a better panel arrangement for GCA approaches."

385. Final Approach Visibility Studies
Fiscal Year 1952, Progress Report, Part I
Prepared by U.S. Weather Bureau for
Air Navigation Development Board (ANDB proj. 4.14)
Washington, D. C.
June 30, 1952 43 pp. (0)

"The project was planned and implemented as the result of discussions held between representatives of the Air Navigation and Development Board (ANDB) and the Weather Bureau in the spring and summer of 1951. Discussions centered around possible means of achieving maximum airport utilization. It was realized that weather conditions are vital factors in the problems of increasing the safety of landing and take-off operations of aircraft, of minimizing the relative frequency of missed approaches, and of maximizing the acceptance rates of airports. Consequently, particular emphasis was placed upon the importance of observations in marginal weather conditions, when ceiling and visibility values become critical to flight operations. (The terms 'visibility' and 'visual range' are used interchangeably in this report * * *.) The need for further detailed investigation of these values was agreed upon. Accordingly, the ANDB agreed to sponsor a Weather Bureau project for research and development work on methods of determining ceiling and visibility factors which affect the operation and control of aircraft during final approach and landing, particularly under low-ceiling and low-visibility conditions. The project was activated on October 10, 1951, when preliminary arrangements were completed in accordance with Memorandum of Agreement entitled "Final Approach Visibility Studies," ANDB Project 4.14, dated September 14, 1951.

"This first progress report outlines the initial phase of the work accomplished by the Weather Bureau on the project from October 10 to December 31, 1951. The scope of this report embraces mainly the description of the instruments at hand for measuring ceiling and visibility, with some discussion of their limitations together with an analysis of the problem and plans for field investigations possible with available facilities and instruments. Activities during the specified period consisted principally of recruiting personnel, formulating plans for the conduct of the project, and installing observational equipment."

386. Instrument-Control Configurations
Affecting Performance in a Com-
pensatory Pursuit Task
Simon, Charles W.
Antioch College
Wright Air Development Center
Wright-Patterson AFB, Ohio
AF Technical Report No. 6015
Feb. 1952 40 pp. (0)

"The presence of an interaction between the zero position of the pointer and the location of the control was found to affect performance in a single compensatory pursuit task.

"Sixteen different pointer-control combinations were used. These were composed of four zero positions of the pointer, one in each of the cardinal points about the dial, and four control conditions - a rotary knob located below the dial, a short lever located below the dial but extending upward from its pivot point, a lever as before but extending downward, and a lever located above the dial extending downward. With the control separated vertically from the instrument dial, a clockwise movement of the control resulted in a clockwise movement of the indicator pointer in the same plane. Deflection of the pointer was less than 45° on either side of the target point.

"Three design principles were found to facilitate higher performance scores with the vertical lever. These were (1) aligning the pointer with the vertical lever control, (2) arranging the relative positions of the pivot point and moving end of the display pointer so that they correspond to those of the lever control, and (3) having the moving end of the lever directed toward the dial. Various pointer-control combinations yielded equivalent results. Results and implications are discussed."

387. The Relative Detectability of
Red-Purples, Reds, and Yellow-Reds,
in Air-Sea Rescue
Sexton, Mary S., Florence L. Malone,
and Dean Farnsworth
U. S. Naval Submarine Base
New London, Connecticut
Medical Research Laboratory Report No. 195
March 1952 9 pp. (0)

"This study investigated the relative threshold visibility of a graduated series of light red-purples, reds and yellow-reds (from 5 RP 6/6 and 6/10 to 10 YR 6/6 and 6/10, unmodified by atmospheric attenuation.

"Observations were made outdoors in sunlight at distances of thirty-five to one hundred and ninety feet. The test colors were $1/4$ " circles mounted on blue-grey boards representing the color of the ocean under two different weather conditions.

"Colors within the range of reds (10 RP to 10R) proved more visible than other colors of the same brightness and chroma. Colors displayed against darker backgrounds were detected at much greater distances than when they were displayed against lighter backgrounds of similar contrast ratios.

"The effect of factors other than hue which should be considered in the selection of colors for maximum visibility under search conditions at sea are discussed."

388. Developments in Submarine and
Small Vessel Lighting
Farnsworth, Dean
U.S. Naval Submarine Base
New London, Connecticut
Medical Research Laboratory Report No. 209
September 1952 6 pp. (0)

This report considers types of lighting fixtures and instrument illumination systems used in modern submarines. It also discusses the general basis for requiring red lighting for the purpose of safeguarding dark adaptation. In addition, general objectives of good lighting are discussed.

389. Radar Display Research at the
RAF Radar Research Unit
Bartlett, Sir Frederic
Flying Personnel Research Committee
The Psychological Laboratory
Cambridge, England
August 1952 4 pp. (0)

"(1). The radar design engineer and the radar operational officer are of necessity principally concerned with the amount and type of information which the normal observer can be reasonably expected to extract from a full display whose features are mainly predetermined by engineering possibilities.

"(2). Consequently they correctly attempt to rate, or otherwise score, performances on whatever display they are interested in and, by comparing overall scores when whatever minor modifications of particular features of the specific display may be possible are used, to settle the best practical display of this type.

"(3). But:

"(a) There is no assured way of rating or scoring extremely complex overall performances.

"(b) The extracting of information demanded is demonstrably being influenced all this time by a mass of fluctuating conditions, many of them of an 'unwanted' kind, and even if most of these can be identified, their fluctuations remain largely unpredictable.

"(c) In the result little can be learned except on a basis of elaborate and often disputable statistical analysis.

"(d) In spite of the prolonged investigations of this type carried out by many people in many places, there are as yet hardly any assured known principles which can be used to solve problems of developing radar design in the field of display.

"(4). During the last nine months the Cambridge Radar Display Research Group has been experimenting with an approach based upon the use of 'reduced' and controlled display situations which can be explored so as to gain knowledge of what it is worth looking for when subsequent advance is made step by step to the fully realistic display. Experimental results are described which, though tentative as yet, can justly be claimed to promise a reasonable chance of successful development."

390. Psychological Research
at the Institute of Psychiatry,
Maudsley Hospital
Technical Report ONRL-134-52
Prepared by C. H. Graham,
Office of Naval Research, London
December 3, 1952 (0)

Among other programs of psychological research at the Institute of Psychiatry, Maudsley Hospital, is the work under Contract No. BuMed N625585-56 with the U.S. Navy Bureau of Medicine and Surgery. "The contract was instituted for the purpose of 'conducting research and constructing a battery of tests which will give maximum discrimination between normal and abnormal groups.' Analysis depends heavily upon the methods of factor and criterion analysis.

"An interesting aspect of the program centers about the types of test being investigated. Rather than paying attention to inventory-type items, the experimenters are emphasizing tests of a perceptual sort. Some (but not all) of these are described below:

"(1) Dr. Brengelmann is carrying on a preliminary investigation on the subject's course of adjustment to curvature induced by prisms. When 20° prisms are placed over the eyes, base-out (to the left eye) and base-in (to the right eye), the subjects' estimates of curvature decrease as the prisms remain over the eyes for longer and longer times. It is tentatively hypothesized that the amount of adjustment shown will be different in normal and abnormal subjects.

"(2) A second test measures a subject's accuracy in dropping a dart on a target while prisms are worn. Accuracy increases as time of wearing the prisms increases.

"(3) A third test concerns the estimation of the vertical as dependent on the head position.

"(4) A fourth test consists of projecting an after-image upon a surface angled with respect to the frontal plane. The apparent size of the after-image varies with the angle of surface. It is assumed that normal subjects will show a greater degree of size constancy than will abnormal people.

"(5) A fifth test involves the tachistoscopic presentation of objects. The experimenter determines the duration threshold and the number of presentations required by the subject to 'recognize' the presented object. Some preliminary data indicate that abnormal subjects may need more presentations and longer durations of the stimulus for recognition than do normal subjects.

"(6) Other tests involve a tactual Poggendorf illusion and a tactual matching of distance for 'divided' and 'undivided' space. Preliminary results indicate that abnormal subjects make greater errors than do normal subjects.

"Dr. Granger is considering the place of visual tests in the program.

"(7) In a first experiment, dark adaptation thresholds are determined by the Admiralty Research Laboratory Adaptometer (Mark III A), at 5-minute intervals throughout a period of 30 minutes. Dr. Granger has accumulated data on about 130 normal subjects and 40 abnormal subjects, the latter evenly divided between neurotics and psychotics. He is loath to discuss the preliminary results but feels that the tentative evidence does indicate that normal subjects have lower thresholds than abnormal subjects.

"Dr. Granger expects to carry out other experiments on hue discrimination, flicker, acuity and muscular balance. He hopes that, if precise results are obtained, it may be possible to specify more exactly than heretofore some of the underlying sources of behavior variation on the 'normal-abnormal' continuum.

"The experiments under this contract are well under way but no final outcome can be stated at the present time. The results of the factor and criterion analyses must await the accumulation of the test data."

391. Quantitative Instrument Reading as a Function of Dial Design, Exposure Time, Preparatory Fixation, and Practice
Christensen, Julien M.
WADC Aero Medical Laboratory
Wright-Patterson AFB, Ohio
WADC Technical Report 52-116
Sept. 1952 51 pp. (0)

"The present experiment is the first of a series undertaken in an effort to determine the nature and significance of certain variables involved in the reading of dials. The subjects were required to read various types of dials at selected exposure times without knowledge of which one of the various dials used in the experiment would be exposed next. Six variables were considered in this experiment, viz., Subjects, Exposure time, Practice, Moving Pointer vs. Moving Scale, Clockwise vs. Counterclockwise Rotation, and Point of Fixation. All effects were significant singly and/or in combination with other effects. Subjects interacted with all other variables, either singly or in combination. Exposure time was shown to be an exceedingly powerful and important factor. Relationships discovered at one exposure time became insignificant or even reversed at other exposure times. This interaction between dial type and exposure time casts serious doubt on the practice of inducing errors in dial reading experiments by the expedient of reducing exposure time. Some of the interactions changed with practice, showing the importance of level of training in experiments of this nature. Moving pointer dials were better than moving scale dials at exposure times of the same order as those used by pilots in actual flying situations. Dials with clockwise scales were generally superior to dials with counterclockwise scales."

392. The Effects of Brightness and Color of Illumination on Performance of a Complex Perceptual-Motor Task
Spragg, S. D. S., and Joan Kanwisher
University of Rochester
WADC Technical Report 52-203
July 1952 13 pp. (0)

"This report describes experiments which measured performance in flying a Link Instrument Trainer as a function of the brightness and color of the illumination provided. Subjects (9 in Experiment I, 12 in Experiment II, and 4 in Experiment III) flew modified 'Charley' courses in a task that was almost entirely visual. Performance was measured in terms of deviations from the calculated perfect course in altitude, compass heading, air speed, and vertical speed. In Experiment I, task brightnesses of 0.01, 0.1, and 1.0 foot-lamberts were employed, using white (Mazda) light. In Experiment II, three colors of illumination were used (red, orange-red, and orange-yellow) each at 0.01 and 0.1 foot-lamberts. In Experiment III, subjects flew continuous four-hour sessions with data recorded during the first and fourth hours of each session. White and orange-red illumination was used, each at 0.01 and 0.1 foot-lamberts.

"The results showed color of illumination to be an unimportant variable in this task, provided that the colors used were equated for brightness. As for brightness, each of the three experiments yielded superior performance at the higher brightnesses but the differences were in several instances not statistically significant, due chiefly to variability in performance of the task and to variability due to the instrument.

"It is concluded that the results in general corroborate previous findings from this project with respect to dial reading performance as related to illumination variables."

393. Factors Affecting Legibility of Digits
Schapiro, Harold B.
University of Rochester
WADC Technical Report 52-127
June 1952 17 pp. (0)

"This study was concerned with the manner in which the legibility of single digits (as measured by speed of reading) is affected by the interactions of the following variables: Level of illumination, style of digit, and ratio of stroke-width to over-all height of digit. Illumination levels used were: 0.011, 0.044, 0.145, and 0.975 foot-lamberts. Digit styles were: AND 10400, Berger, Craik, and Mackworth. Stroke width - height ratios were: 1:5, 1:6.25, 1:8 and 1:10.

"Twelve subjects with good vision each read 3200 digits in a factorially designed experiment. Analysis of the results showed that: (1) in the determination of legibility, level of illumination was the most important factor studied in this experiment; there was a marked improvement in performance from 0.011 to 0.044 foot-lamberts, but relatively little additional change for brightness levels higher than this; (2) the Mackworth digits were the most legible with the AND 10400 digits a very close second; (3) ratios of 1:5 and 1:6.25 were superior to others tested; and (4) except for illumination level, differences between subjects were more important than any other source of variability in the experiment."

394. The Associational Value of Aeronautical Chart Symbols
Koponen, Arthur, Rolland H. Waters, and Jesse Orlansky
Dunlap and Associates, Inc., Stamford, Conn.
Office of Naval Research Report 641-05-7
July 1952 36 pp. (0)

"Purpose

The purpose of this study is to develop procedures by which meaningful aeronautical chart symbols, insuring rapid and efficient chart reading, can be devised and evaluated.

"Procedure

The associational values¹ of chart symbols were determined through five consecutive steps:

1. Collection of samples of original symbols for a series of objects.
2. Separation of these symbols into five general categories.
3. Determination of the best symbol in each category for each object.
4. Determination of the rank order preferences for each object.
5. Comparison of the selected symbols with conventional symbols.

With the exception of step two, these steps were carried out through the use of tests administered to Naval and civilian subjects. Step two was accomplished through the examination and classification of the responses obtained in step one.

"On the basis of the results obtained through these five steps, the symbols appearing

on WAC charts were evaluated by the authors with respect to their associational values.

"Conclusions

1. Effective chart symbols should quickly bring to mind the objects they represent.
2. Symbols may be categorized as a pictorial likeness, part of the whole, verbal, related object or geometric.
3. Subjects select symbols in the category of pictorial likeness most frequently and symbols in the category of related object least frequently.
4. Naval and civilian subjects do not differ in the types of responses given.
5. The majority of the symbols appearing on the WAC charts have a low associational value.

"Recommendations

1. Symbols should have a common meaning that can be immediately interpreted by most people.
2. Whenever possible, symbols should be pictorial likenesses of the objects they represent.
3. New symbols should be tested experimentally before being adopted.
4. The findings of this study, together with known facts concerning the effects of size, form and color upon readability, should be applied in the development of new chart symbols."

¹The associational value of a symbol may be defined as its ability to evoke an immediate and correct response of the object it represents.

395. An Evaluation of Two Experimental Charts
Designed for Navigation in High-Speed,
High-Altitude Aircraft
Murray, John E., Rolland H. Waters, and
Jesse Orlansky
Dunlap and Associates, Inc., Stamford, Conn.
Office of Naval Research Report 641-05-6
May 1952 78 pp. (0)

"The objective of this study was to evaluate two experimental charts designed for use in navigating high-speed, high-altitude aircraft.

"The evaluation procedures included readability tests, under daylight and night lighting conditions, and questionnaires designed to elicit pilots' opinions about which chart they preferred. In one set of readability tests, the World Aeronautical Chart (WAC) was also included to permit a comparison of the experimental charts with a traditional chart.

"The results indicated that both experimental charts were superior to the WAC in presenting information for cross-country missions in jet aircraft. The two experimental charts appear to be similar to each other. However, each chart has several features which proved superior in presenting certain types of navigational information to the pilot."

396. The Symposium on the Physiology and Pharmacology of Receptors and Nerve Endings at the Opening of the New Physiology and Pharmacology Laboratories, Kungl. Veterinärhögskolan, Stockholm
Graham, C. H.
Office of Naval Research, London
Technical Report ONRL-113-52
December 1952 (0)

"Introduction"

A 'Symposium on the Physiology and Pharmacology of Receptors and Nerve Endings' took place on the occasion of the opening of the new physiology and pharmacology laboratories of the Kungl. Veterinärhögskolan, Stockholm, on December 5 and 6, 1952. The highly informative program was arranged by Professors C.G. Schmiterlöw and Y. Zotterman of the Pharmacology and Physiology Departments, respectively.

"The laboratories are housed in a newly constructed building of three stories. The first floor contains storage rooms, animal rooms and shops, as well as a large well-appointed lecture room with every sort of teaching aid. The second floor contains the pharmacology laboratory, equipped with new and modern laboratory devices to meet a wide range of research and instructional needs. The third floor houses the physiology laboratory. The latter laboratory contains a fine supply of electronic apparatus for electric recording and stimulation, as well as a good collection of standard equipment for research and teaching purposes. The laboratories are not only well designed but, in addition, they provide comfortable quarters and offices for the staff and research workers. They provide an unusual setting for scholarly investigation and instruction.

"Summaries of some selected papers"

E. D. Adrian, Cambridge: Sensory Messages and Sensations.

Adrian reviewed some early history in the recording of sensory impulses. In general, it seems that the sensory discrimination of intensity is correlated with nerve impulse frequency, but the problem of the correlates of such other discriminations as shape, "quality" (e.g., color), etc., has not yet been clarified. (In vision, the problem may not be so complex as it is in other senses.)

In olfaction, the temporal and spatial patterning of sensory input may be important in determining sensory 'quality.' Adrian discussed some recent experiments. Olfactory stimuli result in responses in the olfactory lobes. Different chemicals give responses that are differently localized. For example, acetone gives strong responses at the front of the olfactory lobes while amyl acetate gives strong responses at the back of the lobes. In general substances that are soluble in water have a low response threshold at the front of the olfactory lobes, while substances soluble in lipoids have a low threshold at the back. It is possible under certain conditions to record different spikes in response to different kinds of stimulation from the center of the lobes. Such an analysis seems to differentiate 'qualities'. The time courses of response vary for different substances. 'Quality' in olfaction seems to be correlated with place and pattern of response.

S. Burleigh and A. Forbes, Boston: Retinal Response to Sudden Color Change.

Burleigh and Forbes ask the question: What happens in the electroretinogram when a wavelength is instantaneously substituted for another wavelength as a stimulus and the energy of both wavelengths is adjusted to give equal visibility. Burleigh and Forbes indicate that with such a change in stimulus the record shows an off effect due to the first stimulus and an on effect due to the second. (Controls were instituted to evaluate relative rod-cone contributions in the frog eye. In addition, experiments were performed with the rod-free turtle eye.) The results indicate that different colors set up responses in relatively independent neural color pathways. The on and off effects do not occur when the same wavelength is substituted for itself.

W. Rushton, Cambridge: The Measurement of Visual Purple in the Living Eye

Rushton described a method designed to measure visual purple in the living eye. Light directed into the eye is twice absorbed and the amount transmitted can be compared with a comparison source. Under appropriate conditions, the measured amount transmitted can be established as that which remains after absorption by the visual purple. Rushton has performed some experiments on rabbits where, in some cases, an estimate can be made of

the change in visual purple density occurring during dark adaptation. The method is new and in a preliminary stage of investigation. If one set of data are correct, visual purple absorption in the rabbit eye is about 30 to 40%.

C. Enroth, Stockholm: Fusion Frequency and Impulse Frequency in the Light Adapted Retina.

Critical fusion frequency was studied as a correlate of impulse frequency in the light adapted retina. Records were obtained of ganglion spike frequencies recorded by a micro-electrode. Fusion frequency was taken to be the frequency at which the on and off discharges become asynchronous with the intermittent light stimulus. Impulse frequency was measured as the initial frequency of these discharges. Over a wide range of intensity, Enroth shows that fusion frequency is a linear function of impulse frequency. A theoretical basis for this relation is not obvious, but its usefulness is clear.

A. Wirth, Milano: Application of Electroretinography to the Analysis of the Visibility Function.

The visibility curve for the rabbit is established by recording the energies of various wavelengths required to give equal b-waves in the electroretinogram. Visibility curves thus obtained show higher values in the red than would be expected on the basis either of the absorption data on visual purple or psychophysical experimentation.

D. Ottosson and G. Svaetichin, Stockholm: The Electrical Activity of the Retinal Receptor Layer.

Electrical activity in various retinal layers was recorded by means of microelectrodes sunk to various depths into these layers. The question was asked: What layers give the ERG? The ERG remains in the presence of cocaine when the microelectrodes record activity in the end-organ layer of the frog. When the electrodes are sunk into the bipolar layers, responses characteristic of these layers are recorded. Cocaine removes the bipolar responses. Further analyses showed that different forms of ERG may be associated with rod and cone-activities. Ottosson and Svaetichin's controversial paper attributes a major part of the ERG to the receptors."

397. The Dazzle Effect of an Atomic Explosion at Night
Whiteside, T.C.D. and K. Bazarnik
Flying Personnel Research Committee
RAF Institute of Aviation Medicine
May 1952 10 pp. (0)

"1. The glare problem of an atomic explosion is discussed. The problem was investigated under the effects of:

- (a) local stimulation as when the flash is in the subject's visual field;
- (b) diffuse stimulation as when the explosion is behind the subject;
- (c) the effect of increasing the instrument brightness.

"2. The method of using the sun for producing the same degree of retinal stimulation is described. The apparatus is described.

"3. It is found that with a stimulus subtending $7 \frac{1}{2}^{\circ}$ (central fixation) and of duration $\frac{1}{25}$ second, the visual process obeys the reciprocity law when the brightness-time product is 30 candles/cm²/second.

"4. The technique is discussed and it is regarded as capable of giving useful results. It is pointed out that the results given are probably pessimistic when certain other variables are considered.

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"5. It is found that a pilot is able to control his aircraft (Harvard and Mosquito) for at least 15 - 20 seconds with the eyes closed even where the trim has been deliberately altered by the observer.

"6. The pilot may be blind for only several seconds or for several minutes, particularly in good visibility and if he is near to the flash, but if the level of instrument illumination is sufficiently high this time may be reduced to 20 seconds or less.

"7. It is recommended that there should be available in case of need, white flood-lighting of the instrument panel; that this lighting should be controllable by means of a rheostat, and that with it the lowest brightness of instrument markings should be 5 equivalent foot-candles.

"8. The control of this lighting should be by an on-off switch which immediately gives maximal illumination. Purely by touch, it should be possible to locate it, recognize it, and to know whether it was on or off. A sphere mounted on some form of toggle switch would probably be the most satisfactory shape providing there is no other switch of similar shape in the cockpit."

398. Pilot Performance During Extended Periods
of Instrument Flight

McIntosh, Billy B., John L. Milton, and
Edward L. Cole

WADC Aero Medical Laboratory

Wright-Patterson AFB, Ohio

AF Technical Report 6725

May 1952

42 pp.

(0)

"The purpose of this investigation was to collect exploratory data on pilot performance during extended instrument flights. Each of three pilots flew a C-47 aircraft for ten, fifteen and seventeen hours respectively. Equipment installed in the aircraft permitted recording of (1) amount of time flight indicators were kept within tolerance limits, and (2) continuous variation of flight indicators and control positions. Pilots' introspections and observations by a safety pilot were also obtained after each flight. To supplement the above measures, addition, illusion, and reading comprehension tests were given before, during and after the ten hour flight, pilot reaction time to a signal light was taken during the fifteen hour flight and an alertness indicator was operated during the seventeen hour flight.

"The time within tolerance results indicate that the pilots kept the flight indicators within the specified tolerance limits for both precision maneuvers and straight and level flight as well after ten, fifteen and seventeen hours of instrument flight as they did during the first hours of these flights. The results of the graphic records also gave indications that performance, as measured, was not a function of time, since no decrement appeared between the first and last portions of the flight. The introspections of the pilots indicate that they became preoccupied with their physical discomfort but they believed they could cope with a critical situation had it appeared. The constant level of their performance indicates they were coping satisfactorily with the flight requirements."

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399. Factors in Night Vision Sensitivity:
The Effect of Brightness
deGroot, Sybil G., Jane M. Dodge, and
Jo Ann Smith
Medical Research Laboratory
U. S. Naval Submarine Base, New London, Conn.
MRL Report No. 194
March 1952 17 pp. (0)

"Night sensitivity of the eye was explored by using a spot of light of different brightnesses presented at nine points between one and twenty-seven degrees from fixation in each of four positions: Up, down, right, and left. A total of 13,000 judgments were made by three observers.

"Overall sensitivity was found to increase rapidly to a peak between seven and twelve degrees from fixation and then to decrease steadily into the periphery. Sensitivity in the upper, lower, nasal and temporal quadrant follow the same general pattern but with certain specific differences. The nasal quadrant had the best sensitivity over the largest area."

404. An Analysis of the Candlepower
Distribution Requirements of
Runway Lights
Gilbert, Marcus S. and H. J. Cory Pearson
Civil Aeronautics Administration
Technical Development and Evaluation Center
Indianapolis, Indiana
Tech. Dev. Report No. 178
June 1952 19 pp. (0)

"This report discusses the runway light candlepower distribution based on the functional requirements for adequate guidance of various types of commercial aircraft during circling, approaching, landing, taxiing, and take-off operations conducted in accordance with Civil Air Regulations.

"Individual aircraft characteristics were considered in establishing positional limits between which different types of aircraft might be expected to operate during various maneuvers. After consultation with a number of pilots, assumptions were made concerning which lights a pilot should be able to see for guidance during each operation. The directions and distances between the lights and the successive aircraft positions were then calculated and tabulated.

"Critical atmospheric transmissivities were assumed in conformity with existing regulations governing operations under various weather minimums, and the corresponding candlepower requirements were then determined. These candlepower requirements were then evaluated in order to determine their practicability and in order to determine whether intensities needed for some airplane positions in space would cause glare at other positions.

"Finally, acceptable candlepower (cp) values were plotted as isocandle curves which can serve as a basis for performance specifications for improved runway lights."

405. The Influence of "Adaptinol" and
Vitamin A on Night Vision

Imus, Henry A.

Research Units for Nutrition and for
Observations, National Defense Research
Council of the Netherlands.

Office of Naval Research, London

ONRL Tech. Report ONRL-73-52

July 1952

3 pp.

(0)

"'Adaptinol' is the Bayer trade name for a solution in oil of the dipalmitin acid ester of xanthophyl which was used by German investigators for the improvement of night vision. Various studies on the effects of 'Adaptinol' have been reported. These studies are all incomplete. Most of them refer to very small groups of subjects whereas no comparisons are made between large groups with and without dosages. For these reasons, measurements were made for several weeks of night vision capacity of three groups of 25 men aged between 19-22. The Goldmann-Weekers adaptometer was modified to meet our specification as to the shape, size and possibility of rotation of the test object by the manufacturer Haag-Streit of Bern. The night vision capacity was determined by measuring the threshold intensity after dark adaptation for 30 minutes.

"The members of the three groups were given respectively 10 cc. 'Adaptinol' solution 1/2 per cent in salad oil, 10 cc. cod liver oil containing 5000 I U vitamin A and 10 cc. salad oil for fourteen days. During the week preceding the period of dosage, measurements of the night vision capacity for all the test persons were obtained for the sake of comparison.

"In the period of dosage the 'Adaptinol' group was measured daily, the two other groups once every two days. After the period of dosage, the measurements were continued for three weeks.

"The concentration of vitamin A and carotene in the blood was determined before the experiment started, at the end of the period of dosage and at the end of the experiment. The analysis of results leads to the following conclusions:

"1. All groups demonstrate a slight improvement in night vision capacity and vitamin A concentration in the blood probably due to uncontrolled conditions of the general activity and a slight improvement of the nutrition.

"2. The carotene concentration of the blood of the adaptinol group increases considerably during dosage and comes down to normal values within three weeks after dosage.

"3. The vitamin A concentration of the vitamin A group does not change significantly from that of other groups.

"4. The influence of temporary intensified activity is apparent by a temporary decrease in the night vision capacity. This variation exceeds the slight improvement mentioned under (1).

"5. No significant differences in the behavior of night vision capacities between the three groups were found.

"6. No significant correlation between the vitamin A or carotene concentration and the night vision capacity could be detected in a comparison of the results for all subjects.

"7. The average values of night vision capacity in terms of threshold energies for the

test object used are in the same region of intensities as reported by other investigators.

"8. The average concentrations of vitamin A and carotene in the blood for the three groups at the beginning of the experiments were rather small."

406. Research in Physiological Psychology
Imus, Henry A.
Office of Naval Research, London
Technical Report ONRL-74-52
July 1952 3 pp. (0)

The following are abstracts of some of the papers presented at the meeting of the Physiological Society of Great Britain, held at Cambridge on May 17, 1952. It is expected that reports of these researches will appear subsequently in the regular journals.

"On the Functional Stability of the Retina, E. J. Denton and M. H. Pirenne, Physiology Department, University of Aberdeen.

"On the basis of measurements of the visual threshold of *Xenopus laevis* for continuously exposed fields 30° in diameter (Denton and Pirenne, 1951), it may be calculated that a response can be produced by a retinal illumination such that each rod is struck on the average by one quantum of $\lambda = 0.55\mu$ every 4 sec. For man, the corresponding figure for absolute threshold is one quantum of $\lambda = 0.51\mu$ per rod every 1000 sec. Since such feeble stimuli are effective, it seems probable either that the rods are not undergoing spontaneous excitation at a high rate or that such excitation is different from that caused by light. Although the eye is insensitive to its own black-body radiation (Fick, 1879; Pirenne, 1951), the fineness of the nervous processes of the rods might have led one to expect 'biological noise' (Fatt & Katz, 1950) to occur in them.

"In the human eye, the differential threshold (ΔI) increases rapidly with the background intensity (I) even when (I) is near the absolute threshold. Thus König and Brodhun (1888) found for a field $3^\circ \times 4.33^\circ$ that when $I = 0$, $\Delta I = \Delta I_0$. This would hardly be understandable if the background of spontaneous excitation were equivalent to more than the feeble excitation caused by light at the absolute threshold.

"It was found in *Xenopus* that a temperature rise of 20° C did not affect significantly the absolute value of the threshold for 0.55μ . In experiments made on different days, the log threshold in arbitrary units was: At 9° C, 3.1, 3.0, 3.5, 3.3; and at 29° C, 3.2, 3.0, 2.9, 3.1. These results refer to a field $1^\circ 40'$ in diameter with 100 quanta striking a given rod every second.

"Earlier investigations have shown that, compared to quantum fluctuations, biological variations play only a minor role in experiments on the probability of seeing a near-threshold flash of light (Hecht, Schlaer and Pirenne, 1942; Pirenne, 1951).

"Thus, even though spontaneous activity is often observed in electrophysiological work on the retina, the above considerations suggest that the visual system, when functioning under the best conditions, is not only very sensitive but also is very stable."

"A New Visual Pigment Absorbing Maximally at $510 m\mu$, H. J. A. Dartnall, Group for Research in the Physiology of Vision, Medical Research Council, Institute of Ophthalmology, London.

"Visual pigment solutions, prepared from retinae of dark-adapted bleak (*Alburnus lucidus*), have absorption characteristics lying within the limits given in the literature for

'visual violet.' Nevertheless, by the method of partial bleaching it has been found that they contain a mixture of photosensitive substances.

"By exposure to light of long wavelength, a red-sensitive component, consisting principally of visual pigment 533, can be preferentially removed. The remaining red-insensitive component can then be bleached by exposure to light of shorter wavelength.

"Bleaching the red-insensitive component in stages reveals that it is a single pigment ($\lambda_{\max} = 510 \pm 3 \text{ m}\mu$).

"This pigment has a difference spectrum similar to, but significantly distinct from, that of visual pigment 502 (the 'visual purple' of *Rana temporaria* and *R. esculenta*).

"Visual pigment 510 (*Alburnus lucidus*) follows Beer's and Lambert's laws of light absorption, and has a photosensitivity comparable with that of visual pigment 502 as well as a similar thermal stability. Its difference spectrum, when plotted on a frequency scale, is of the same shape as those of all known visual pigments. Like them, it partially regenerates in darkness after bleaching."

"Nerve Impulses in the Locust in Response to Visual Stimuli, E. T. Burtt and W. T. Catton, Departments of Zoology and Physiology, King's College, Newcastle-upon-Tyne.

"Parry (1947) reported large action potential spikes in the circumoesophageal nerves of the locust in response to movement of objects in the visual field of the compound eye. Burtt and Catton have found similar potentials in the ventral nerve cord of the locust only as far down as the third thoracic ganglion. A few fibers much larger than the rest have been identified in sections of the nerve cord. Potentials arose in response to two types of stimulus: (a) Switching on or off the general illumination (insect in a darkened cage), and (b) movement of objects across the visual field of a compound eye. Experiments have been carried out on the second type of response in an attempt to assess the acuity of movement perception of the locust. The minimum angular movement of a point source of light with respect to the eye which gave a detectable response was found to be about $1/3^\circ$, in both vertical and horizontal planes. The angular divergence of the optical axes of adjacent ommatidia, measured by a simple optical method, was found to be about 1° in the vertical and 2° in the horizontal plane."

407. The Institute of Optics in Madrid
Hyde, Lewis W.
Office of Naval Research, London
Technical Report ONRL-41-52
May 1, 1952 6 pp. (0)

The following are excerpts from Dr. Hyde's report:

"The social disruption caused by the Civil War, and by the Second World War, severely interrupted the progress of science in Spain. In the last few years the Spanish government has made a vigorous effort to remedy this situation. A number of large and well equipped buildings have been built in Madrid to house a series of scientific Institutes. One of these is the Institute of Optics, 'Daza de Valdes,' described in this report.

"The Institute of Optics, whose address is Serrano, 121, is one of a large group of very impressive scientific buildings in a group about two miles from the center of Madrid. It was built about five years ago in a blend of modern and Spanish architecture. The laboratories and workshops occupy four stories and a basement. On the top floor there is an attractive lounge and open terrace overlooking Madrid, much used by the Members of the Institute.

"About forty scientists work at the Institute at this time. In addition to the scientists, there are a number of students, most of them working on degrees at the University of Madrid. There are also technicians, machinists, and a maintenance and secretarial staff. The annual budget of the Institute is about two and one half million pesetas a year, i.e., about fifty thousand dollars at the free market rate of exchange. The support of the Institute is from the Superior Council of Scientific Investigation (Consejo Superior de Investigaciones Cientificas) which is under the Ministry of Education of the Spanish government.

"The Director of the Institute is Dr. Jose M. Otero. The Institute is divided into a number of sections as follows:

Section 1	Vision	J. M. Otero
Section 2	Technical Optics	Franz Weidert
Section 3	Spectra	Miguel Catalan
Section 4	Physical Optics	Leonardo Villena
Section 5	Electron Optics	Justo Manas
Section 6	Photography	Maria Vigon

These Sections are further subdivided into groups working on special topics. The secretary of the Institute is Dr. Saez Breton.

"Two particularly important pieces of work are going on at the Institute at this time. The first of these is a series of studies in physiological optics under the direction of Otero. The second is studies in atomic spectra under the direction of Professor Catalan. To a large extent the activities throughout the rest of the Institute can be characterized as preparatory rather than productive. That is to say, the lack of scientific tradition and the destruction of scientific material has forced the people to spend a disproportionately large fraction of their time building elementary instruments, re-doing basic experiments, and training personnel in preparation for more advanced work.

"The research in physiological optics is under the close personal supervision of Otero. Under him are two groups:

"a. Physiological Optics: Otero, Mariana Aguilar, Miguel Solis, Pepita Yunte.

"b. Colorimetry: Dr. Lorenzo Plaza, Jorge Catalan.

"The primary work of Otero's group has been on the phenomena of night myopia and dark adapted vision. He and his colleagues have made valuable contributions in this field, both in the measurement of night myopia and in the solution of the problem of its origin. Important results were produced by Otero and A. Duran as early as 1941 and a long series of papers appeared during and after the war. Recent investigations include a study by Otero and Aguilar on the change in visual acuity as the illumination approaches threshold, and a study of the minimum illumination at which sensation of color first appears. These experiments have been reported in The Journal of the Optical Society of America.

"The colorimetry section under Dr. Lorenzo Plaza is commencing a series of experiments to determine the change in chromatic value of a pigment as it is viewed at various angles from the normal. This is an important effect when certain practical problems in color matching are considered, and it has not been properly studied previously. Dr. Plaza has spent one year at the National Bureau of Standards where he participated in important experiments concerned with color vision in the various possible forms of color television. The results of this work in the United States have been published in American scientific journals.

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"An earlier experiment by Otero and Plaza concerns a novel method for the precise determination of the index of refraction of optical components by an immersion method combined with interferometric observation. Plaza has also assisted Otero in experiments to determine the influence of spherical aberration on night myopia of the human eye. These experiments have demonstrated conclusively that the spherical aberration of the eye is not the prime cause of night myopia.

"Special mention should be made of the unusual attainments of Dr. Jose M. Otero, the Director of the Institute. He studied physics at the University of Berlin and has travelled widely throughout Europe. Since the war his scientific and administrative talents have led him into a large number of responsible positions. He is now the Director of the Institute of Optics, and in addition is Director of the Naval Research Laboratory. He is also the Vice-President of the Commission on Nuclear Energy and in this position is responsible for the scientific and technical portion of their activities.

"Otero has also been active in the founding and organization of a commercial optical instrument factory now under construction near the Naval Research Laboratory. He is a member of the Board of Directors of this firm and has been delegated by the Board of Directors to supervise the planning and building. At present the capital for this firm is supplied by the government but it is planned to seek private sources of capital after the factory is in production. It is hoped that this factory will take over the manufacture of optical instruments now concentrated in the Naval Research Laboratory, and that it will also be able to supply the civilian market and thus free Spain from its dependence on foreign sources of optical instruments.

"Otero holds the rank of Lieutenant Colonel in the Ordnance section of the Spanish Navy and his duties in this position include both the direction of the Naval Research Laboratory, and lecturing at the Naval Ordnance College. In addition to his teaching duties at the Naval Ordnance College, Otero frequently lectures on scientific subjects at the University of Madrid.

"For his many contributions in science and administration, Otero has been honored many times by the Spanish Government, the most recent being the award of the Cross of Alphonso the Tenth, "El Sabio." His present attainments suggest the great capability of the Spanish people in science and management, but are also an example of the extent to which talented people are forced to spread themselves thin because of the lack of scientific tradition and the disruption resulting from the Civil War."

408. Qualitative Observations of the
Visual Behavior of Cats Deprived of
Their Visual Area in the Cortex
 (A preliminary report of research
 by Ralph Gunter)
 Prepared by Imus, Henry A.
 Office of Naval Research, London
 Technical Report ONRL-78-52
 5 August 1952 2 pp. (0)

"The absolute lower threshold for vision, the spectral sensitivity under dark adaptation (rod function) and the spectral sensitivity under light adaptation (cone function) have been determined in four cats by Dr. Ralph Gunter, at the Institute of Ophthalmology. These animals were then subjected to an ablation of their occipital areas and the sensitivity data were redetermined.

"At first Gunter ablated the visual areas as mapped out by Marshall & Talbot. When the animal had recovered, there was no observable change in behavior from the normal

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animals. These cats would jump from tables, would avoid obstacles and would show all the general behavior patterns of normal animals. The visual reflexes, as well as nystagmus, could be elicited easily in these animals.

"The same general results were obtained when the area, generally known as the striate area, was removed from the cortex. Under experimental conditions in the choice box, these animals showed the same ability to discriminate between lights of different intensities as they had done when they were normal. All of these observations refer to conditions of light as well as to dark adaptations.

"Next, Gunter extended the ablations a considerable distance anteriorly as well as laterally, and in some cases removed as much as three quarters of the cerebral hemispheres. These animals showed a striking change in behavior compared with the normal. They seemed absolutely blind in daylight, that is, they ran into obstacles, they did not jump when put on a table, they showed no placing reactions of the fore-legs and nystagmus could be elicited only with great difficulty. The pupil reaction to light was sluggish at first, but returned to normal and there was very little following movement in the eyes. All of these reflexes will be tested again.

"In the choice box these animals did not learn to discriminate between different intensities of light after 2000 trials (normal learning time required 200 trials). Animals which did discriminate before the operation lost this habit after the operation and the function did not recover. This was under conditions of light adaptation.

"Under conditions of dark adaptation the spectral sensitivity of these animals, as well as their absolute lower threshold, were not altered significantly from the values obtained on the same animal when normal. The tentative conclusion to be drawn from these observations (pending histological examination of the brains) would be: (1) that the area responding electrically to photic stimulation of the eye is not the sole center for vision; (2) cone vision (light adaptation) seems to be destroyed when an extensive amount of cortical tissue is removed; (3) rod vision (vision under conditions of dark adaptation) is not affected by this operation and does not seem therefore to be localized in the cortex."

409. Papers Presented to the Experimental
Psychology Group of Great Britain
Imus, Henry A.
Office of Naval Research, London
Technical Report ONRL-88-52
26 August 1952 3 pp. (0)

The following are summaries of three papers presented to the Experimental Psychology Group of Great Britain at the July 1952 meeting:

The Suppression Theory of Binocular Vision, H. Asher.

"On the usually accepted fusion theory of binocular vision it is held that a single mental impression is produced by fusing the impression of stimuli falling on disparate retinal points. This theory is critically examined, and it is shown that if the theory is true then there must be a relative change of local sign of elements from the two retinae. From suitably placed marks on stereo-cards evidence is found that no such relative change in local sign does occur.

"The Suppression Theory is stated as follows:

"The two retinae are composed of pairs of corresponding points whose correspondence is completely rigid and unchanging.

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"One of a pair of corresponding points always suppresses the other.

"When there is disparity of contour, then in the one eye the contour, including an area on either side of it, will suppress the corresponding retinal points in the other eye. If the suppression is sufficient in extent in relation to the disparity between the contours, then one contour will be suppressed and there will be single vision with depth perception. The contour of one part of the image may be dominant in the one eye and that of another part may be dominant in the other eye.

"The claim is made that this theory brings into the same category the following phenomena:

- "1. Suppression of the white ground, as commonly observed when combining pictures of the parrot and cage variety.
- "2. Enhancement of suppression in the neighborhood of contours.
- "3. Enhancement of the brightness of white near a black border.
- "4. The reduction of visual acuity in the parafovea.
- "5. The shape of the combined stereo-diagram being intermediate between the shapes of the two pictures.
- "6. The difficulty of the binocular fusion of colors.
- "7. The occurrence of depth perception with diplopia."

The Psychology of the Frog's Retina, H. B. Barlow.

"Much of the characteristic visual behavior of the frog is governed by the physiological properties of its retina. One, therefore, has an opportunity of investigating the physiological mechanisms behind some simple psychological reactions. Existing anatomical and physiological techniques fail to show any essential difference between the nerve cells of complicated nervous ganglia, such as the cerebral cortex, and simple ones, such as the retina: the simple structures offer a better opportunity to get an idea of the kind of things that a nerve cell, or an assembly of cells, can do. The retina converts the image cast on it by the lens into nerve impulses which travel up the optic nerve. It is possible to detect these impulses so that one can study the relation between a controllable stimulus - light falling on the retina - and the resulting response - action potentials in the optic nerve.

"The relationship in the frog is not a simple one, and the pattern of impulses in the optic nerve is not a simple copy of the pattern of light and shade on the retina. First, the impulses tend to occur only when the light falling on the retina is changed; if a bright object or shadow is moved across the retina the nerve fibers coming from that part of the retina discharge. Thus nerve impulses signal movement, and this is clearly related to the fact that frogs show visual responses only to moving objects. Second, each fiber picks up from a large area of retina, and these areas, or receptive fields, must overlap each other to a very large extent. The retina will be most efficient in detecting objects of such a size that their image just fills a receptive field; it can be argued that a ganglion cell specifically sensitive to moving objects of a particular size is an elementary device for 'recognizing' the frog's food. Finally, the relation between stimulus and response is not a rigid one, but depends on the past history and present condition of the retina; in the human eye the differential threshold stays close to the theoretical limit set by the amount of visual purple from absolute threshold to a background level 10,000 times absolute threshold. This adaptability is achieved by neurological changes, not by changes of visual purple concentration, and it is

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possible to regard the adaptation to changed conditions as an elementary form of learning."

Simultaneous Vision and Audition, G.H. Mowbray.

"The relative performance of vision and audition under conditions of simultaneous stimulation by conflicting material was investigated. Rapid auditory and visual scanning tasks requiring the detection of elements missing from familiar, overlearned sequences were used. Performance on the simultaneous trials was compared with nonsimultaneous performance of the same conditions.

"The main findings indicate that deterioration of performance (i.e., decrease in successful detections relative to nonsimultaneous performance) due to the conflicting nature of the simultaneous tasks is not significantly different for either sense modality. Significant differences in deterioration of performance that do occur are attributable instead to the level of task difficulty. When a difficult task is paired with an easier one, the deterioration of performance is greater for the easier of the tasks."

410. A Survey of the Research Literature
 Comparing the Visual and Auditory
 Presentation of Information
 Day, Willard F. and Barbara R. Beach
 University of Virginia
 AF Technical Report No. 5921
 Wright-Patterson AFB, Ohio
 November 1950 14 pp. (0)

"Aeronautical engineers have recently raised the question of the feasibility of devising a system of visual message presentation to supplement or replace the auditory system now used in aviation communication. Prerequisite to research on the development of a visual message presentation system would seem to be an experimental comparison of the visual and auditory senses as channels of communication. Antecedent to a series of laboratory studies comparing the relative intelligibility of messages presented aurally and visually, a survey of the existing research literature in this field was undertaken. An answer to two questions was sought from previous investigations: (1) Is material better understood when presented visually or aurally? (2) Under what conditions and to what extent has one sense modality been found to be superior to the other?

"About one half of the reported studies yield evidence for the superiority of visual presentation; the other half of the investigations supports auditory superiority. It is obvious that the findings have been determined by the specific conditions of each experiment. Relevant factors appear to be the following: familiarity, degree of meaning, and difficulty of material; method of measuring comprehension (i.e., by ease of learning, or amount retained); and various characteristics of the observers (e.g., age, intelligence, social background, reading ability). A principal advantage of visual presentation springs from the possible referability which it affords. Combined visual and auditory presentation is more efficient than is either sense alone. In order to determine more specifically the relative superiority of the two senses for communication purposes, five specific areas of investigation are suggested in the present report."

411. A Facilitative Effect of Red
 Light on Dark Adaptation
 McLaughlin, Samuel C., Jr.
 U. S. Naval School of Aviation Medicine
 U. S. Naval Air Station
 Pensacola, Florida
 26 May 1952 7 pp. (0)

"For each of ten subjects, the degree of dark adaptation attained after twenty minutes in total darkness was compared with that attained after ten minutes in red light and ten minutes in darkness. The average threshold for all subjects was .151 log micro-micro-lambert lower following the combination of red-light exposure and total darkness than after a similar period in total darkness. It is concluded that at least a part of the total process of visual dark adaptation proceeds more rapidly in the presence of red light than in darkness, and this conclusion is shown to be in accord with other published experimental findings. The theoretical and operational potentialities of this facilitation phenomenon, as well as some hypotheses concerning the mechanism underlying it, are discussed."

412. Papers by Toshimasa Hanaoka
on melanophore hormone and its
effect upon scotopic vision.

Dr. Lorrin A. Riggs has called our attention to the following two papers by Toshimasa Hanaoka, of the Laboratory of Physiology, Institute of Health, Nara Women's University, Japan: (a) "Effect of melanophore-hormone upon the scotopic vision of human eye." Jap. J. Physiol., 2, 9 (1951); and (b) "Preliminary note on the effect of melanophore hormone upon the regeneration of visual purple in situ." Annot. Zool. Jap., 24, 137 (1951).

Hanaoka claims to have shown (a) that melanophore hormone extracted from the bull frog accelerates regeneration of visual purple in situ in the Japanese toad; and (b) that injection of melanophore hormone in the human accelerates dark adaptation and increases terminal dark adapted sensitivity. The maximum effect is shown to be a 1000 x increase in sensitivity in the fully dark-adapted eye!! Hanaoka has informed Dr. Riggs that he has had to discontinue his experiments, unfortunately, due to lack of financial support. (Dr. Riggs has reprints of these two articles.)

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